ESL-TR-87-302-02

FIRE FIGHTERS VEHICLE TRAINING SIMULATOR; VOLUME 2

Fire Research Corporation
26 Southern Boulevard
Nesconset, NY 11767

Contract No. F08635-82-C-0419

December 1987

DISTRIBUTION A: Approved for public release; distribution unlimited.

ENGINEERING & SERVICES LABORATORY
AIR FORCE ENGINEERING & SERVICES CENTER
TYNDALL AIR FORCE BASE, FLORIDA 32403

DISCLAIMER

Reference herein to any specific commercial product, process, or service by trade name, trademark, manufacturer, or otherwise does not constitute or imply its endorsement, recommendation, or approval by the United States Air Force. The views and opinions of authors expressed herein do not necessarily state or reflect those of the United States Air Force.

This report was prepared as an account of work sponsored by the United States Air Force. Neither the United States Air Force, nor any of its employees, makes any warranty, expressed or implied, or assumes any legal liability or responsibility for the accuracy, completeness, or usefulness of any information, apparatus, product, or usefulness of any information, apparatus, product, or process disclosed, or represents that its use would not infringe privately owned rights

This document is submitted as an historical record of work performed. Limitations of the available media rendered editing impractical; therefore it is retained "as is."

REPORT DOCUMENTATION PAGE	*Form Approved* *OMB No. 0704-0188*

The public reporting burden for this collection of information is estimated to average 1 hour per response, including the time for reviewing instructions, searching existing data sources, gathering and maintaining the data needed, and completing and reviewing the collection of information. Send comments regarding this burden estimate or any other aspect of this collection of information, including suggestions for reducing the burden, to Department of Defense, Washington Headquarters Services, Directorate for Information Operations and Reports (0704-0188), 1215 Jefferson Davis Highway, Suite 1204, Arlington, VA 22202-4302. Respondents should be aware that notwithstanding any other provision of law, no person shall be subject to any penalty for failing to comply with a collection of information if it does not display a currently valid OMB control number.
PLEASE DO NOT RETURN YOUR FORM TO THE ABOVE ADDRESS.

1. REPORT DATE *(DD-MM-YYYY)*	2. REPORT TYPE	3. DATES COVERED *(From - To)*
15-DEC-1987	Final Technical Report	01-DEC-1982 -- 30-NOV-1987

4. TITLE AND SUBTITLE
Fire Fighters Vehicle Training Simulator; Volume 2

5a. CONTRACT NUMBER F08635-82-C-0419

5b. GRANT NUMBER

5c. PROGRAM ELEMENT NUMBER

6. AUTHOR(S)

5d. PROJECT NUMBER

5e. TASK NUMBER

5f. WORK UNIT NUMBER 25052004

7. PERFORMING ORGANIZATION NAME(S) AND ADDRESS(ES)
Fire Research Corporation
26 Southern Boulevard
Nesconset, NY 11767

8. PERFORMING ORGANIZATION REPORT NUMBER

9. SPONSORING/MONITORING AGENCY NAME(S) AND ADDRESS(ES)
Engineering and Services Laboratory
139 Barnes Drive, Suite 2
Tyndall Air Force Base, FL 32403-5323

10. SPONSOR/MONITOR'S ACRONYM(S) AFESC/ESL

11. SPONSOR/MONITOR'S REPORT NUMBER(S) ESL-TR-87-302-02

12. DISTRIBUTION/AVAILABILITY STATEMENT
Distribution A: Approved for public release; distribution unlimited.

13. SUPPLEMENTARY NOTES

14. ABSTRACT
The Crash Fire Rescue Simulator is designed to duplicate all the operations incorporated in the actual vehicle. The system consists of a number of subsystems which operate in real time to fulfill the goal of the design. The subsystems are Driving Simulator, Video System, Environment Simulator, Fire, Smoke, Foam and Lightning. These systems will are described in detail.

15. SUBJECT TERMS
fire fighting, fire fighting simulator

16. SECURITY CLASSIFICATION OF: a. REPORT	b. ABSTRACT	c. THIS PAGE	17. LIMITATION OF ABSTRACT	18. NUMBER OF PAGES	19a. NAME OF RESPONSIBLE PERSON
U	U	U	UU	106	Joseph Walker
					19b. TELEPHONE NUMBER *(Include area code)*

Reset

Standard Form 298 (Rev. 8/98)
Prescribed by ANSI Std. Z39.18

TABLE OF CONTENTS

TABLE OF CONTENTS (CONT)

TABLE OF CONTENTS (CONT)

TABLE OF CONTENTS (CONT)

TABLE OF CONTENTS (CONT)

1.Ø INTRODUCTION

This report describes the results of an Air Force program to develop a Crash Rescue Vehicle Simulator conducted under contract No. FO8635-82-C-ØØ419. This contract includes three phases of operation; Design, Manufacture and Delivery at Tyndall Air Force Base in Florida. The third phase was completed in October 1987. The system met all the contract specifications as accepted by the U. S. Air Force at Tyndall.

2.Ø GENERAL

Current Crash Rescue Vehicles, especially the P-4 are very expensive to operate. In addition, when they are being operated by an inexperienced crew, the possibility exists foi extensive damage to the vehicle, due to an accident or operatoı error. In addition to these possibilities, the vehicle is out of service and would probably not be available for actual crash rescue operations if an emergency arose during a training session. If Simulators are used instead of P-4 vehicles, the savings will amount to over $2,ØØØ,ØØØ per year. In addition, a Simulator has the ability to present wartime conditions to a student that would not be available in a normal training scenario. These wartime conditions include runway craters, multiple damage in various parts of the airport simultaneously, as from an air attack, building fires and fuel storage facility fires. This kind of training is only available by use of a Simulator.

Because of the high hourly cost of operating crash rescue vehicles for training, as well as the environmental effects of both air pollution and ground water contamination caused by training fires, it is getting more and more difficult to maintain a high degree of proficiency among fire fighting crews. Thus the crash rescue Simulator which proved that such a vehicle. which will produce proficient fire fighting crews, is not only possible, but is highly desirable.

Many variations of designs and components were considered. The final design contains the best elements available at a reasonable cost to building a realistic P-4 Simulator. This P-4 Simulator not only has the ability to simulate all driving conditions normally found on a typical air base but it simulates the fire attack capabilities of a P-4 vehicle.

The initial concept included a large frame surrounding the cab, with the cab being moved within this framework by large air driven cylinders. This design was changed to a much simpler design which utilized a single counter weighted beam and with cab roll and seat motion. The initial system also included a complex 6 lens camera system with optical relays to transmit the video image up to the cameras. This was modified to a fiber optics system in order to simplify the design of the system.. As shown in Figures 2.1 and 2.2, the crash rescue vehicle consists of the following major components.

a) SCREEN: A large 28' diameter by 11' high screen.

b) CAB: The cab of the vehicle which is a composite mock-up of an actual P-4 cab.

c) MOTION SYSTEM: A motion system which given motion to both the cab and the driver's seat to simulate the "G" forces and changing horizon as a result of vehicle motion.

d) PROJECTOR SYSTEM: A projector system, 5 each, high powered color projectors aligned so that each projector projects 1/5 of the total view as seen by the student operators.

e) MODELBOARD: A modelboard which is an 80 to 1 scale of an actual air base. This air base includes hangers, buildings, aircraft, civilian vehicles, crashed aircraft and miscellaneous equipment.

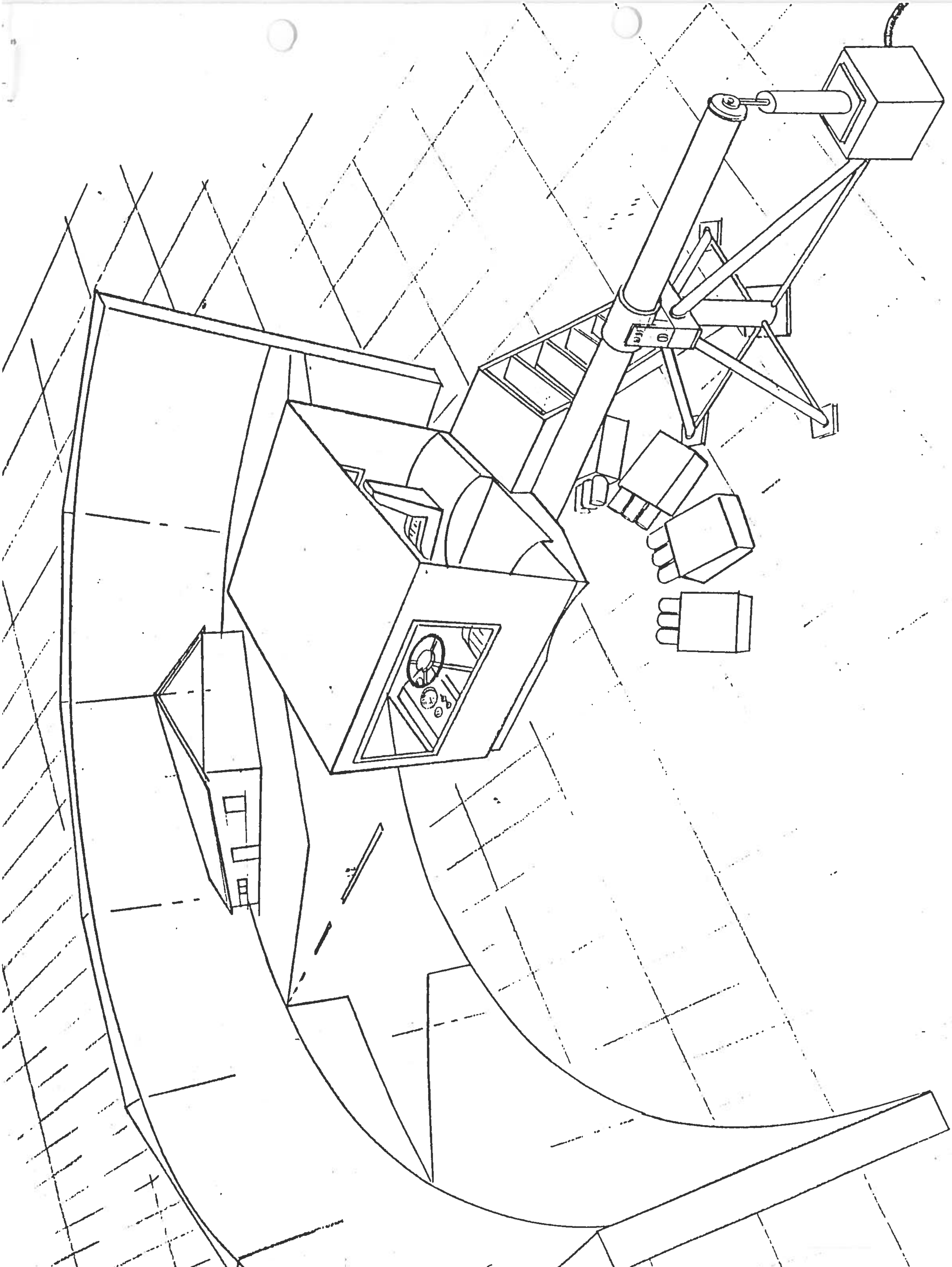
f) CAMERAS: The video pictures represented on the screen are taken by 5 separate CCD cameras aimed through a special lensing system on a movable probe that can be driven around the modelboard under the control of the driver/operator.

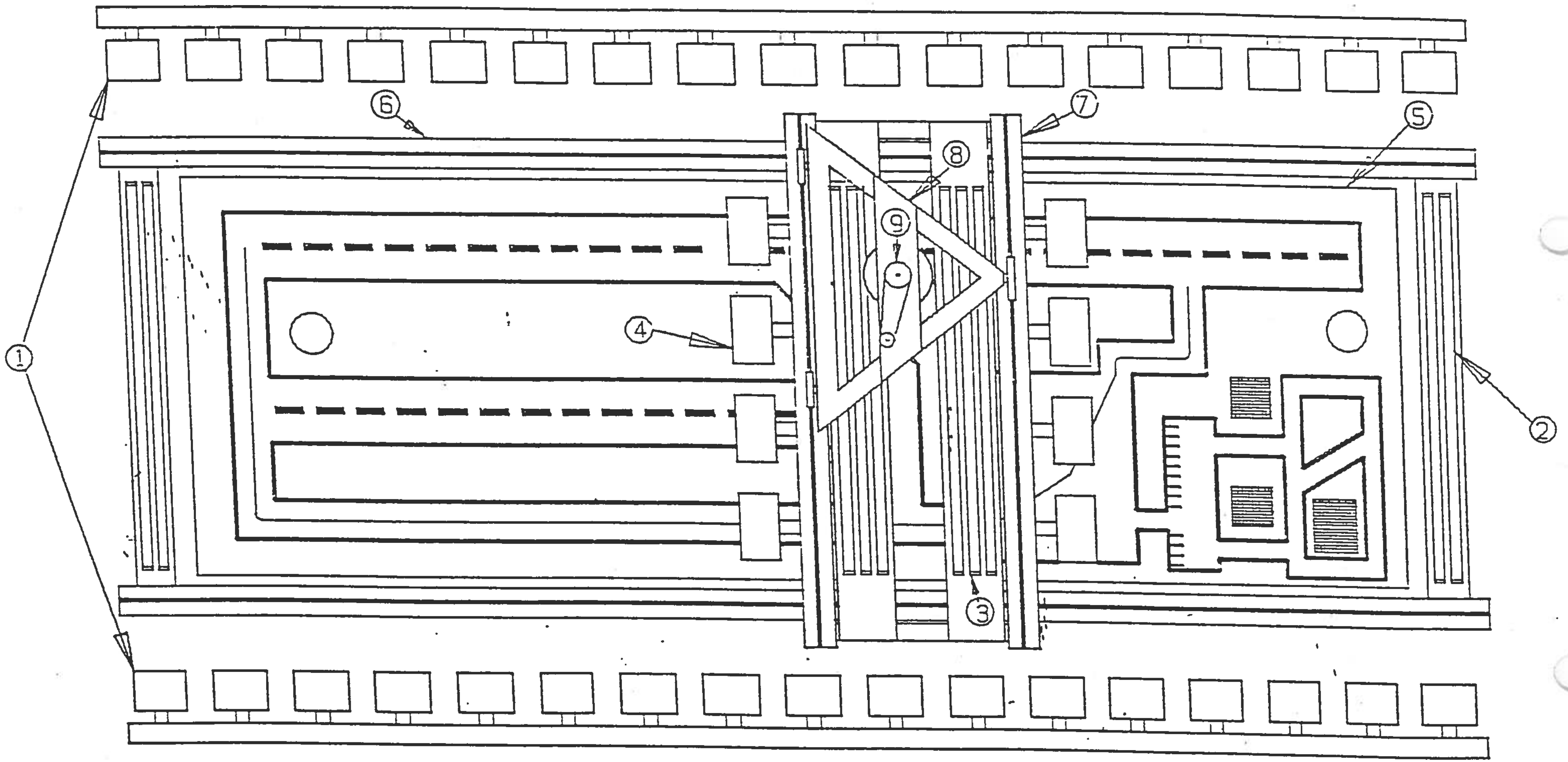
g) OPTICAL SYSTEM: This optical probe consists of a lensing system that has 5 views that are presented at the bottom of a fiber optic bundle with each fiber optic bundle terminating in front of a CCD camera. Thus, each segment of the lens is optically transmitted to a camera and the camera, in turn, transmits this signal to its respective projector.

h) PROBE MOTION SYSTEM: The probe mechanism is propelled around the modelboard under the control of the driver/operator. His inputs to the probe system include steering wheel, accelerator and brake pedal inputs. The driving inputs are fed to a digital computer that operates off an algorithm that converts these inputs to DC signals to operate 3 precision servo mechanisms to control the movable gantry that the optical probe rides on. In addition to the X and Y servo systems, there is a Z or rotational servo system. These servo systems have a very wide turn down ratio which enables the vehicle to drive down a runway quickly in one direction but at the same time, slowly crossing the runway, ie. going from the left side to the right side.

i) SYSTEM DYNAMICS: This vehicle has all the dynamic characteristics of the actual P-4 vehicle. These characteristics were obtained by the actual testing and gathering of data on a P-4 vehicle at Westhampton Air Force Base in New York.

j) SMOKE: To simulate actual fire conditions, a number of avenues were investigated that did not prove to be very workable and were abandoned for that reason. A stage type smoke was investigated which is an oil base smoke. The major problem with that system is that the oil settled on the modelboard and after a few training sessions, the system had to be extensively cleaned. In addition, the smoke also did not behave in the normal manner of fire smoke. It had a tendency to layer itself at ground level. Another system that we tried that produced excellent smoke results was injecting titanium tetrachloride into the air. The smoke results were very good but it was rejected because of the toxicity of the chemical. The system that was settled upon, after a good deal of experimentation, was injecting CO_2 on to a surface of heated water which produces copious amounts of non toxic smoke with zero clean up problems. This smoke was modified by the injection of minimal amounts of Helium to make the smoke





1. Main Lights
2. Sky Light
3. Moving Florescent Lights
4. Moving Quartz Lights
5. Model Board
6. X Track
7. X Gantry
8. Y Gantry
9. Azimuth

GANTRY SCHEMATIC

FIGURE 2.2

rise as would occur in a normal fire operation. This combination resulted in a very accurate simulation of smoke conditions.

k) FIRE: The initial study into the fire simulation was the use of red lights infringing upon the smoke to get the proper flicker effect. This effect was not realistic enough, so after experimentation, a system was developed that utilizes 50 watt Quartz Halogen bulbs projecting through a series of multi-colored lenses that are rotated below the fire area by a DC motor. This combination of elements gives a extremely realistic presentation of a fire to the driver/operator.

l) FOAM SYSTEM: A major portion of crash rescue fire fighting is the application of foam to a burning aircraft. The initial concept called for a nozzle to be able to dispense little glass balls (micro spheres). These would be ejected by air pressure and would behave like foam if observed by a camera. There proved to be two major difficulties with the micro spheres. The first and foremost was the possible toxicity of the spheres. The second was that because of their extreme lightness, after a fire training simulation, the modelboard would have to be carefully vacuumed to collect them. A second system that was devised was the design of a special nozzle that would dispense liquid CO_2 on to the burning aircraft. This is the same principle as a CO_2 fire extinguisher, where the CO_2 comes out as a white material and blankets the fire. After investigating and experimentation, a suitable nozzle was designed and manufactured, such that when CO_2 was discharged from the optical probe, it appears to be dispensing foam from the roof turret. The CO_2 has a tendency to cling to the vertical sides of an aircraft, similar to AFFF. In addition, after the extinguishment of the fire, the CO_2 sublimates and there is no clean up necessary.

3.Ø SYSTEM REQUIREMENTS

3.1 DRIVING

One of the most important aspects of this Simulator is to faithfully reproduce the driving characteristics of the P-4 vehicle. Initial data was obtained from Oshkosh, the manufacturer of the P-4 vehicle and the U. S. Air Force and their fleet of vehicles. From this data acceleration rates, turning radius, vehicle weight, center of gravity and roll and sway characteristics were determined. A test program was carried out at Westhampton Air Force Base, utilizing an actual P-4 vehicle and using both video equipment and standard vehicle meters, obtaining actual data from an in service P-4 vehicle. From this acceleration rates, braking rates, ride characteristics and the gravitational forces due to turns at various speeds were determined. The sound characteristics of the vehicle under these varying conditions was recorded. This data was analyzed and an algorithm developed to simulate the driving characteristics of the P-4 vehicle. This system was developed using all the data available, so that when the student operator steps into the cab of the P-4 Simulator and goes through a driving scenario, it will be duplicating what will normally be seen, felt and heard. The Simulator that was delivered to Tyndall was driven by a number of experienced P-4 operators. The operators agreed that the system faithfully reproduced the driving characteristics of an actual P-4 orientation. The driving algorithm is given in Section 9.

3.2 VEHICLE ORIENTATION

A Simulator of this type is not only useful for dynamic classroom training but it also can be used to orient the student to the positions and functions of the controls of a standard P-4 cab. This Simulator was expressly designed so that a student could go through many dry runs, ie. operate the various control valves and knobs without the Simulator in operation. This way the student will get the feel of each control and will be able to operate it without damage. This is not the case with an actual P-4 vehicle because a student could actually go in and operate controls and damage the system, if it is operated incorrectly.

3.3 SYSTEMS OPERATION

After the student has proven to be capable of driving the vehicle in various off road and on road conditions, with both day and nighttime operations and has mastered all the controls and operations of the fire fighting system, all systems must be utilized simultaneously. The P-4 vehicle is designed to be operated by one man under emergency conditions. This Simulator is designed to duplicate those capabilities. This enables the driver to drive out of the fire station, receive communication in route to the fire and get ready to discharge foam agents when arriving at the crash scene. The Simulator has the requirements to be both an effective driving and fire fighting training aid. This will be shown to be the case as the design is described and the way these designs were achieved in the individual write-ups of the basic components.

3.4 CRASH FIRE FIGHTING

One of the most realistic aspects of this Simulator is the crash fire fighting section. A great deal of design effort and many, many changes were included in this effort to obtain the realism that was achieved in crash fire fighting operations. The vehicle must approach the burning aircraft, using the set guide lines from Air Force procedures. These procedures take into account rescue operations, wind direction and velocity, armaments and terrain. Every one of these requirements have been duplicated on the Simulator.

3.5 LOW OPERATING COST

For any Simulator to be cost effective, it must achieve a low hourly operating cost. The operating cost takes into account manpower required, M. T. B. F., cost of spare parts, energy usage, and consumable usage. This Simulator has proven itself to be a cost effective training device. It requires one operator who will double as an instructor and maintenance technician for the system. Almost all components are commercially available, off the shelf items which can be replaced by any operator after a 40 hour maintenance class. The cost of spare parts, such as the cameras, projectors and servo systems are extremely low, as they are commercially available from industrial supply houses across the United States. The electric usage on this system is less than $5.00 per hour. The CO_2 usage in the training sessions that were operated, also averaged approximately $6.00 per hour.

3.6 NON POLLUTING

For any Simulator in today's environment to be successful, it must be inheretly non polluting. The initial design and proposal included a smoke system that used a vaporized oil to generate the smoke. After initial testing we found the smoke did not have the rising characteristics of smoke from a large fire. In addition, it was found that the smoke left an oily residue on the various components. A design change after a great deal of experimentation was made to use a non polluting CO_2 system. Another major problem that surfaced after the proposal, was the use of micro balloons as originally proposed. Micro balloons are essentially microscopic spheres of hollow glass that give the appearance of fire fighting foam when emitted from a nozzle type device. After investigation and limited use, it was found that these micro balloons, if ingested into the lungs, could pose a health hazard. In addition, there was a massive clean up operation after each fire scenario. Thus, it was necessary to eliminate the micro spheres and, to develop a nozzle that uses liquid CO_2 in the same fashion as a liquid fire extinguisher.

3.7 SIMPLE INSTRUCTOR OPERATION CAPABILITIES

It was determined early on in the design that this system would be operated by an experienced crash crew operator who would have minimal experience with complex electronic systems and computers. With this in mind, a system was developed that requires no formal training in computers or electronics. The operator simply turns on a three phase A.C. power switch which supplies power to the full Simulator and all its components. Next, the operator turns on the computer with a computer reset button and types in one simple command and the system is operating. Some adjustments to the CO_2 system and prepositioning the optical probe to its desired starting point is mandatory. These functions are all described in detail in the Operational Manual. From initial power "On" to system operation, the average is less than 15 minutes.

4.Ø THE CAB

4.1 INTRODUCTION

The initial proposal for P-4 vehicle Simulator, was to use the actual cab of a P-4 fire fighting vehicle. Quotes were obtained from Oshkosh. An investigation for obtaining a P-4 from the U. S. Air Force that was in an accident but without any structural damage to the cab was made. After lengthly discussions with Oshkosh, it was determined that the front end of a P-4 could not be obtained at a reasonable cost or delivery. The second option of finding a vehicle without damage but that was out of service but had an intact front cab also proved fruitless. So it was decided to manufacture a cab. The prints of the P-4 from both Oshkosh and the U. S. Air Force were obtained and it was determined a duplicate model of a P-4 could not be built without having tremendous weight penalties placed upon it because of the structural rigidity of the P-4 vehicle. Since the design required full motion, it is obvious to minimize the weight of the cab.

4.2 THE CAB BODY

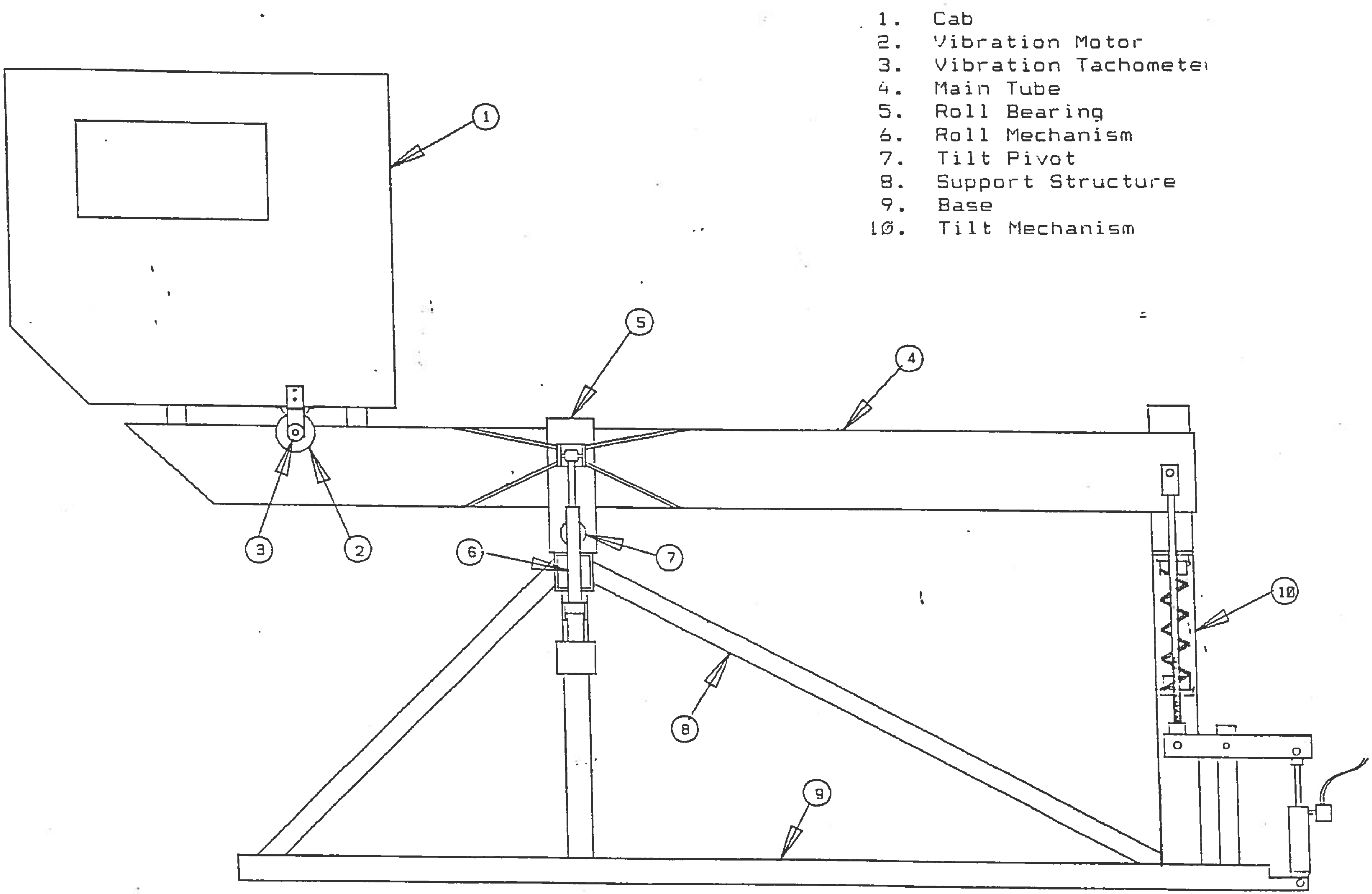
The cab of the vehicle was custom made using a number of different techniques. The cab floor is made of fiberglass which was laid out on a full scale wooden mock-up mold constructed identical to a P-4 cab. This included wheel wells, seat, fixtures, floor slants, etc. The cab floor was built layer by layer using epoxy and fiberglass until the whole floor had a thickness of 1/2". In addition, there was aluminum reinforcing placed as required. The three walls and the roof of the cab were constructed using a different technique. To maintain the weight requirement, a fiberglass/aluminum construction technique was utilized. Each wall and the ceiling was constructed separately. The inner and outer walls consist of identical sheets of aluminum cut to the contour of its specific dimensions. A piece of rigid foam was epoxied between the two sheets of aluminum to give it a tough, lightweight bearing structure. The three walls were at tached to the cab using 6061 T6 angle aluminum for supports at the corners and the roof was attached to the walls using the same technique. The cab has proven to be extremely sturdy and durable. There has been absolutely no problems with the cab structure and it should last well beyond the life expectancy of the Simulator. The windows of the cab are constructed of lexan and are attached to rigid frames which form part of the cab body. They give an excellent simulation of the vehicle windows. The total weight of the cab, including batteries is 800 pounds. (Refer Figure 4.1)

4.3 INSTRUMENTATION AND CONTROLS

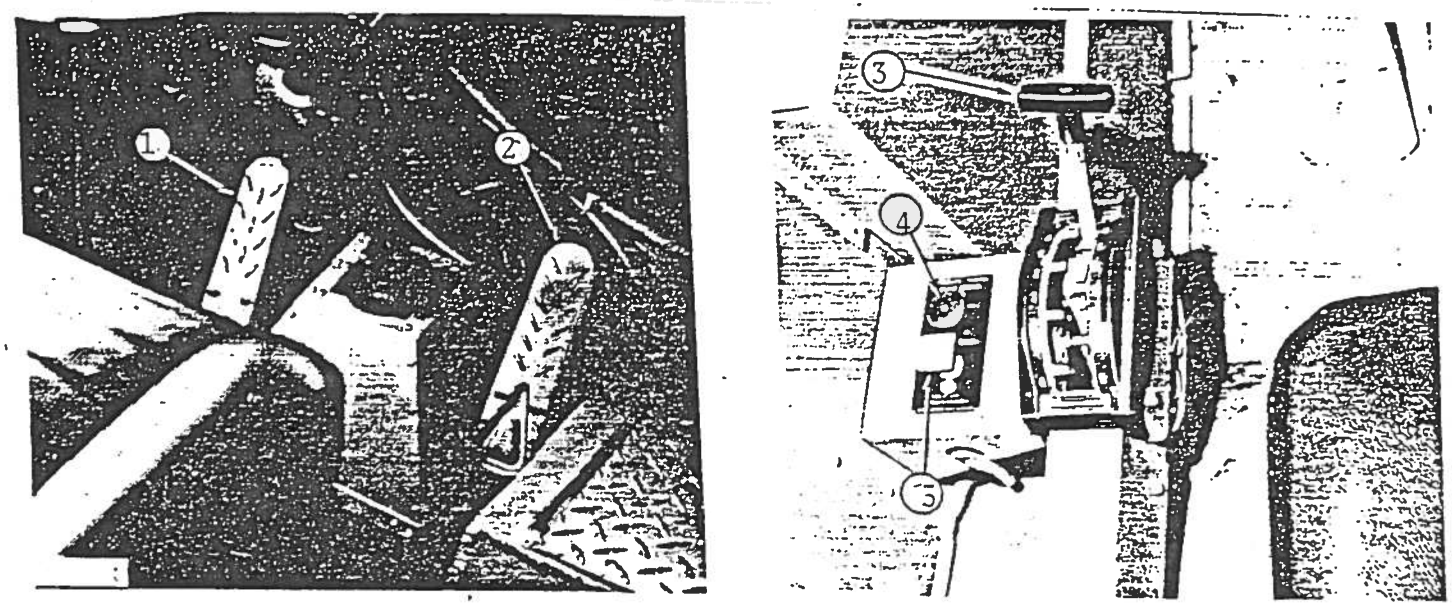
The basic controls for the driver as shown in Figure 4.1, include the following: (Refer Figure 4.2, 4.3, 4.4, and 4.5)

1. Brake Pedal

Since this is a complex vehicle to drive, the brake is operated by the left foot and the gas pedal by the right foot. The brake pedal is a standard spring loaded brake pedal attached to an electrical potentiometer. This potentiometer reads off the amount of force applied to the brakes by the driver and communicates that signal to the computer.



CAB MOTION SYSTEMS SCHEMATIC



Mobile Operation Controls and Instruments

1. Brake Pedal
2. Gas Pedal
3. Gear Shift Lever
4. Parking Brake Control

FIGURE 4.2

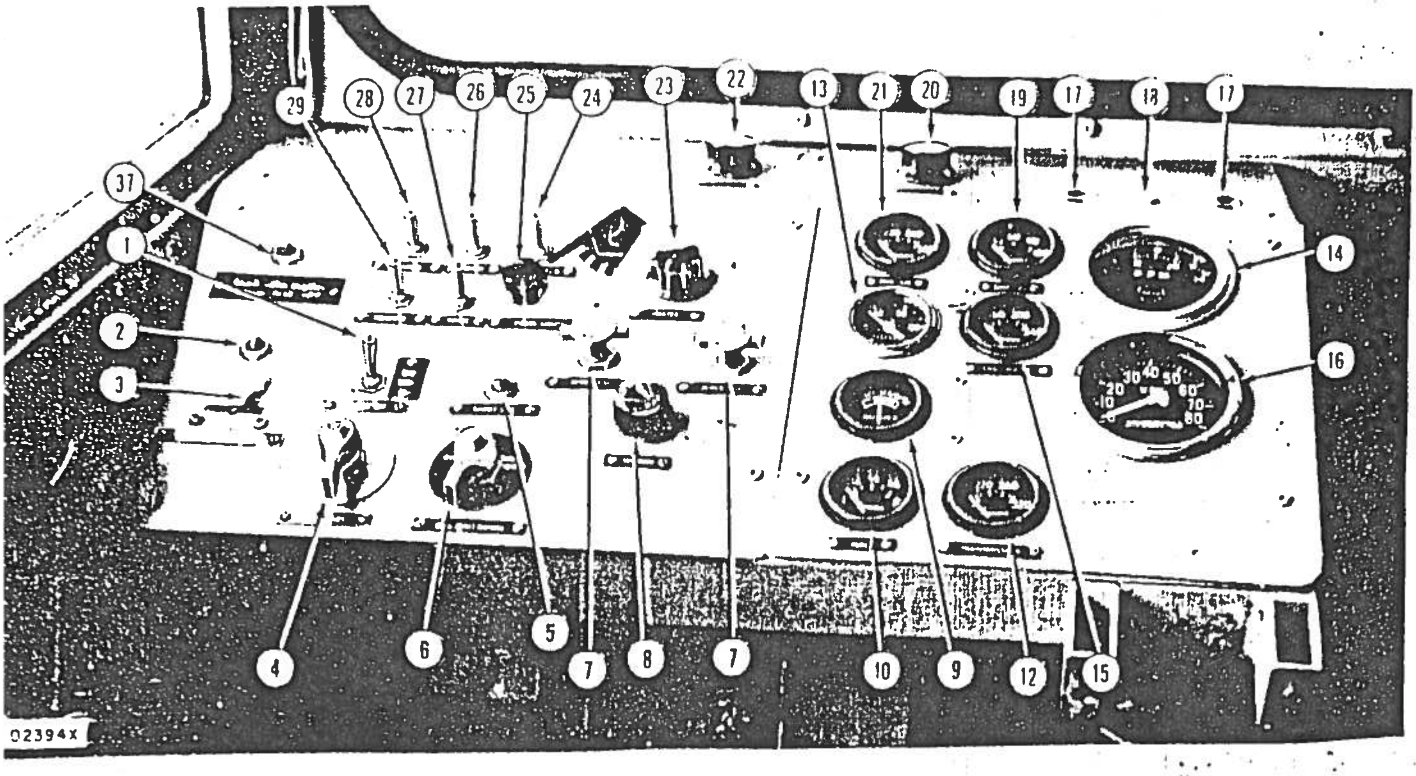


FIGURE 4.3

INDEX NO.	NOMENCLATURE	NORMAL USE OR READING
1	Chassis Electrical master switch	Shuts off all electrical power to vehicle. Push forward for ON.
2	Differential lock indicator light	Illuminated when differentials are locked out.
3	Differential lock control	Locks out axle differential action for better traction under adverse conditions. Push to left for ON.
4	Engine preheat and start switch	Pushed down and turned to left--energizes glow plugs to preheat engine. Pushed down and turned to right--engages engine starter motor
5	Electric system short circuit indicator	Illuminated when short circuit to ground exists in electrical system when master switch (1) is OFF.
6	Engine shut down switch	Turned to left, completes circuit to engine electrical accessories. Turned to right, actuates fuel shutoff solenoid to stop engine.
7	Windshield wiper control knob (2)	Turn counterclockwise to operate windshield wipers (LH knob--driver's side; RH knob--passenger side). Also serves as wiper speed control.
8	Windshield washer control knob	Push down to operate windshield washer spray.
9	Voltmeter/battery condition indicator*	Green range--normal battery charge, normal operation.
10	Fuel level gage*	Indicates quantity of fuel in fuel tank.
11	Turn signal switch lever	Push forward to signal right turn, pull back to signal left turn. Push in tab under lever to flash all signals simultaneously--pull upward on lever to release.
12	Transmission oil temperature gage*	250°F maximum.
13	Air pressure gage*	100-120 psi
14	Tachometer	Engine speed in R.P.M. 2000 maximum
15	Engine water temperature gage*	175°F-185°F.

FIGURE 4.4

INDEX NO.	NOMENCLATURE	NORMAL USE OR READING
16	Speedometer/ odometer	Vehicle speed in MPH/total distance traveled in miles and tenths.
17	Turn signal indicators	Flashing when turn signals are operating.
18	Headlight high beam indicator	Illuminated when high beams are switched on.
19	Engine oil pressure gage*	45 psi--60 psi.
20	RH defroster blower switch	Turn clockwise to operate passenger side defroster.
21	Engine oil temperature gage*	220°F-240°F.
22	LH defroster blower switch	Turn clockwise to operate driver's side defroster.
23	Cab heater control switch	Turn clockwise to start fans and increase fan speed and hot air flow.
24	Rear spotlight Switch	Push forward for ON.
25	Instrument panel light	Turn clockwise to increase panel lights brightness. Fully counterclockwise for OFF.
26	Floodlight switch	Push forward for ON.
27	Dome light Switch	Push forward for ON.
28	Emergency beacon switch	Push forward for ON.
29	Headlight switch	Push forward for ON.

*These gages operate only with chassis master switch in ON position.

2. Gas Pedal

The gas pedal operates in the same fashion and also has a potentiometer that feeds the computer so that the computer knows how much fuel is being applied to the engine.

3. Gear Shift Lever

The gear shift lever is a custom fabricated device with a micro switch at each gear selection point, so that the computer knows via signals from the appropriate micro switch which gear has been selected

4. Parking Brake Control

When activated it sends a signal to the computer to halt all motion and prevent the vehicle from moving.

5. Steering Wheel

The steering wheel turns 3.8 revolutions from stop to stop. The steering control is attached to an electrical potentiometer which feeds the steering wheel position to the computer.

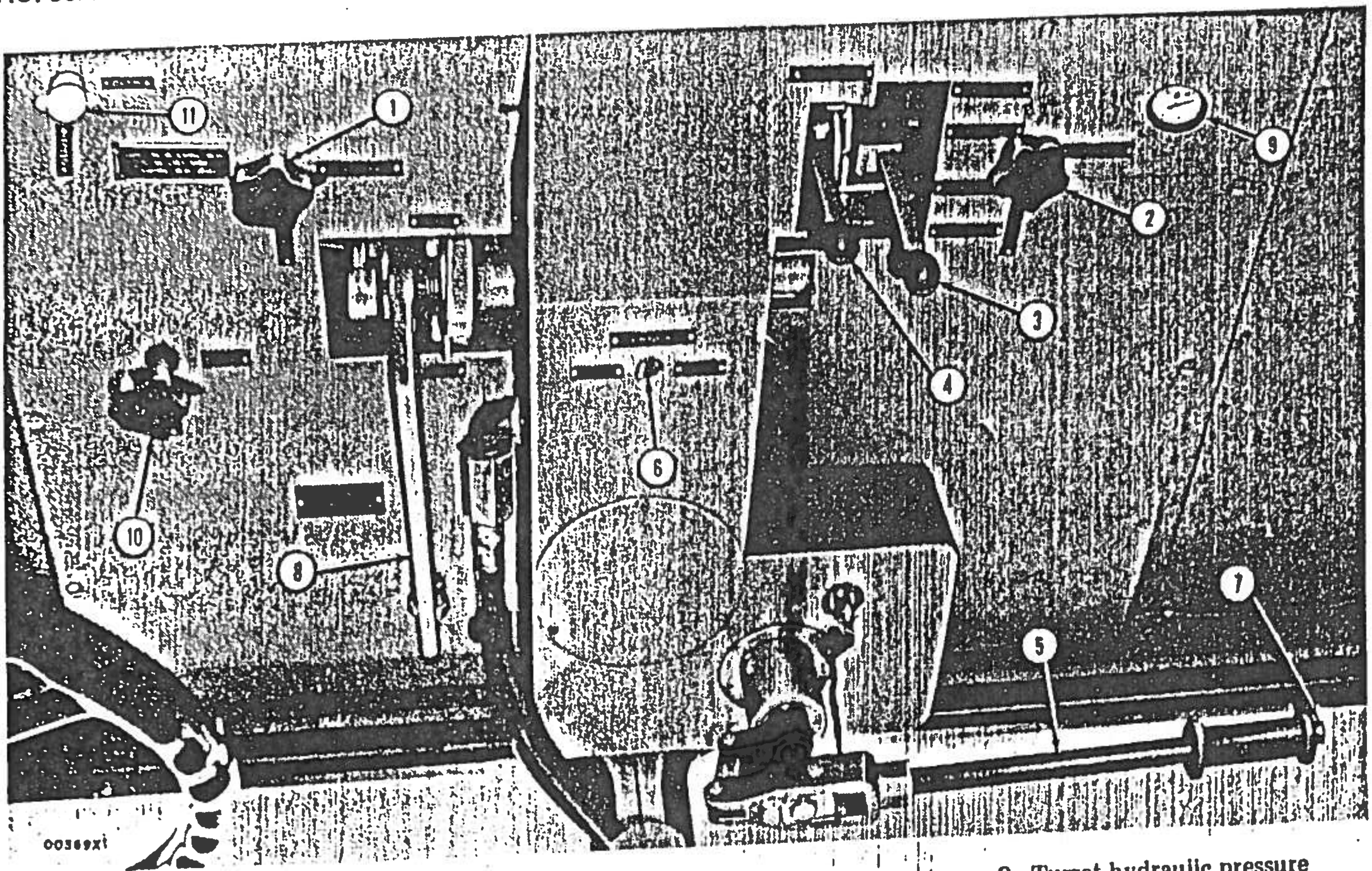
4.4 FIRE FIGHTING CONTROLS

4.4.1 GENERAL

This Simulator is designed to give as realistic a simulation of the actual P-4 crash vehicle operating as a crash truck, as is possible. All of the major components, such as the turret control knob, the turret aiming handles, the discharge valve switch, the discharge rate selector and the pattern selector lever are functional. This system is designed to be used either by the driver or by the crew chief. When the driver arrives at the fire scene, the vehicle is placed in the proper position and the fire is attacked using the roof nozzle system which gives both the feel and the visual effects necessary for a good simulation.

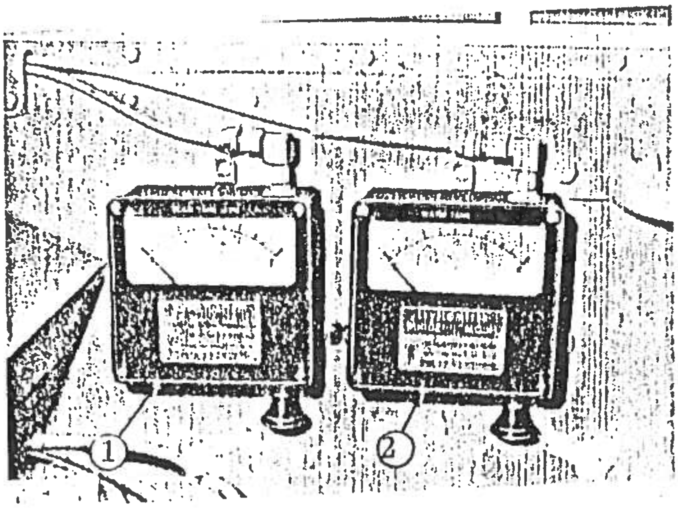
4.4.2 ROOF TURRET CONTROLS

The original design for this Simulator required a dual servo to control miniature nozzle expelling the simulated foam on the burning aircraft. As design progressed it was determined that the servo systems would require excessive amounts of wire going from the cab of the vehicle through the gantry system and then being fed down to the miniature servos. Since this system proved to be very complex, a design change was made to use a high quality radio link from the control knobs down to the servos controlling the miniature nozzle. The turret aiming handle was



1. Discharge valve manual-control knob
2. Turret manual-hydraulic control knob
3. Discharge-rate selector
4. Pattern selector lever
5. Turret aiming handle
6. Discharge valve switch
7. Interrupt button
8. Manual discharge valve lever
9. Turret hydraulic pressure gage
10. Turret lock control knob
11. Agent recirculating valve

FIGURE 4.6



1. Foam Tank Level Gage
2. Water Tank Level Gage

FIGURE 4.7

attached to two potentiometers whose signal was digitized and transmitted at very low power to a receiver on the probe. This receiver decodes the signals and positions the nozzle in a slave fashion to the position of the turret aiming handle. The discharge rate selector an the pattern selector are interwired with the interrupt button on the rear of the turret aiming handle. When all three controls are in the proper mode foam will be discharged at the correct rate. (Refer Figure 4.6)

4.4.3 EQUIPMENT OPERATORS CONTROLS AND INSTRUMENTS

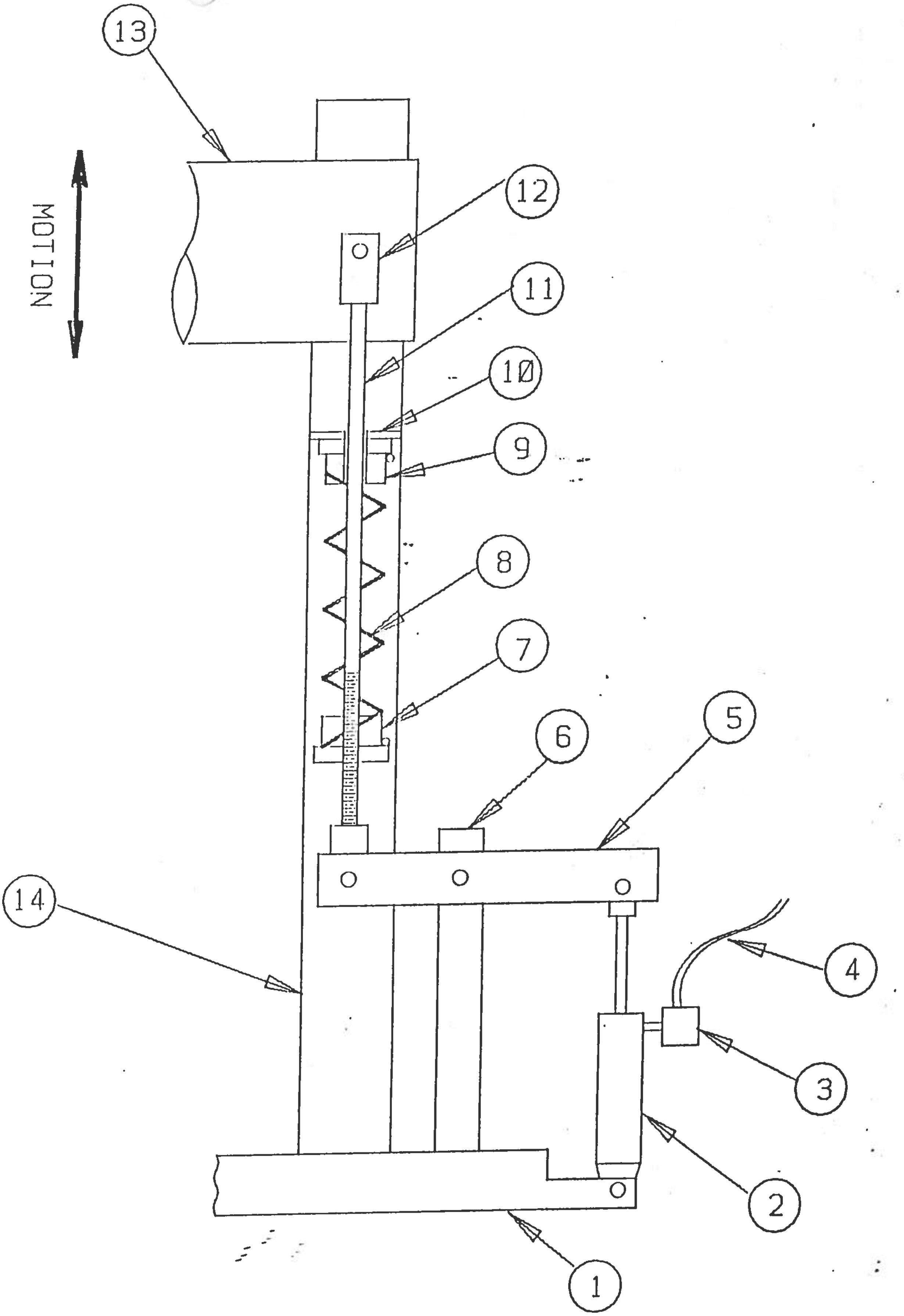
The operator must also observe and control the liquid levels in the tanks, the pump pressure, the agent selector and the various water and coolant temperatures. The liquid level gauges are controlled directly by the instructor. They are Ø-1 milliamps gauges housed to simulate the configuration of the actual gauges. The pump pressure gauge is controlled by the computer and the pressure of the pump is thus determined by the engine speed. The agent selector valve controls either water or foam selection. Its input to the computer is two bits of digital information. (Refer Figure 4.7)

4.5 RADIANT HEATING SYSTEM

As an additional part of the training Simulator, a radiant heating system was installed in the cab of the vehicle. The purpose of this system is to simulate the radiant heat the driver and operator feel as they approach the burning aircraft. As they approach the burning aircraft, the instructor who has manual control turns on the radiant heating system to simulate the effects of the fire energy on the vehicle and its operators.

4.6 MOTION SYSTEM

The motion system has three separate segments. They are pitch (tilt), roll and fore and aft seat motion. These systems required extensive engineering because the prototype, as originally conceived and built did not function as planned. The pitch system was designed using a large three phase 5 Hp. motor eccentrically attached at the opposite end of the cab. The design attempt was if pitch was required, the three phase motor would be operated through a relay contactor, thus giving vertical motion to the other end of the balance pipe that the cab rests on. This system did not prove workable because the contactor was not fast enough to respond to the opening and closing signals of the computer. The motion derived from the electrical motor was



CAB TILT MOTION SCHEMATIC

FIGURE 4.8

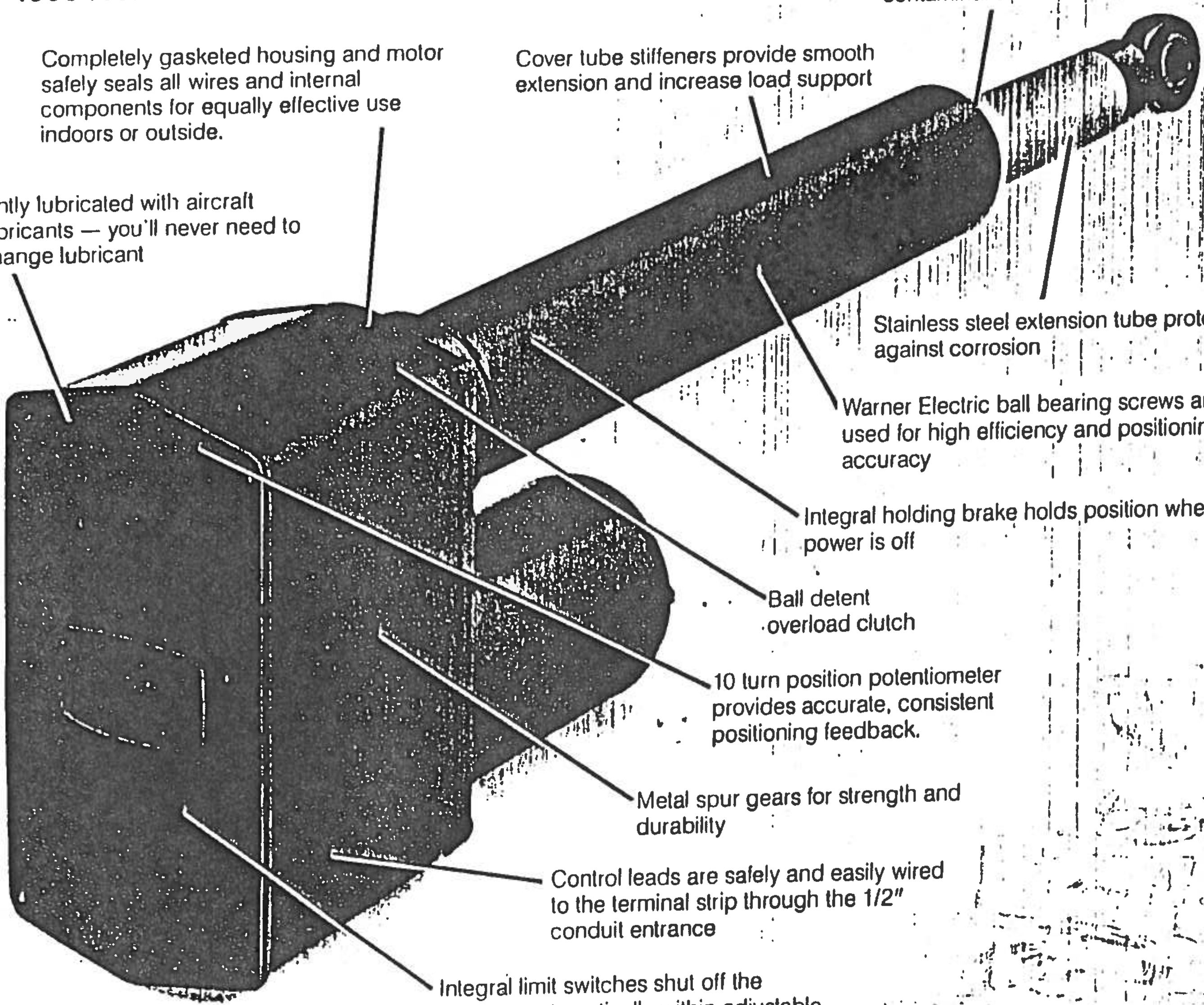
CAB TILT MOTION

1. Cabe Base Structure
2. Air Cylinder
3. Solenoid Valve
4. Air Hose
5. Pivot Link
6. Pivot Link Support
7. Spring Tension Adjuster
8. Spring
9. Spring Arbor
10. Fixed Spring Bearing Plate
11. Connecting Rod
12. Main Tube Connector
13. Main Tube
14. Spring Support & Main Tube Guide

FIGURE 4.9

Electrak 100 — The *complete* DC actuator with feedback

24 VDC
500 or 1000 lbs. max.



e Electrak 100 features a 10-turn entiometer for precise positioning dback to a MCS-2030 or 2035 control t. Multiple step positioning is available en the Electrak 100 is integrated with rogrammable controller system. egral limit switches automatically shut the actuator within the operating ges you set.

ly gasketed housing and motor safely ls all internal components from harsh vironments. Additional O-ring and er seals on the extension tube make the Electrak 100 equally effective for use indoors or outside.

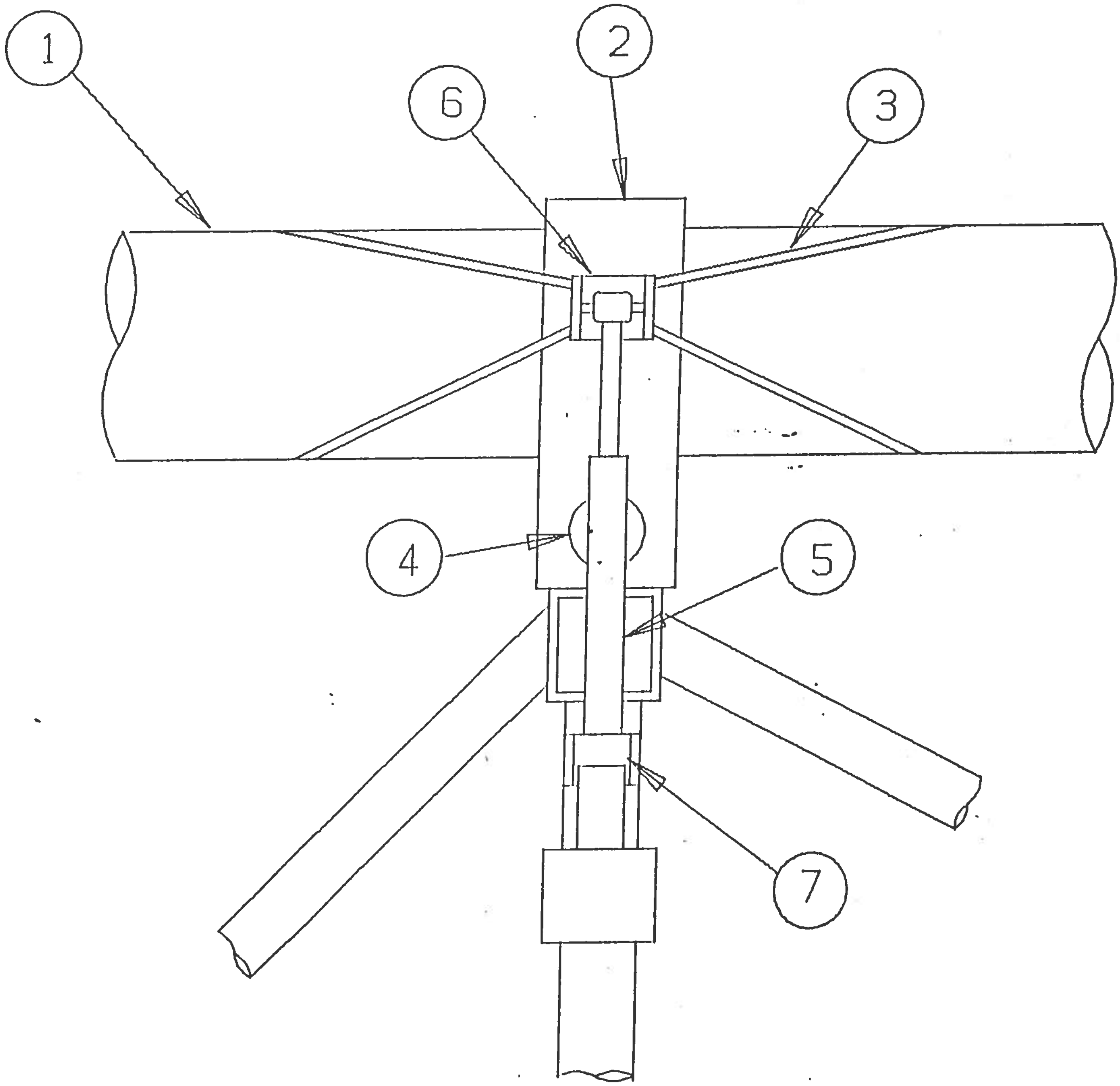
Electrak 100 actuators are available in 2 load ranges; 500 or 1000 lbs. Each range offers stroke lengths of 4, 8, 12, 18, or 24 inches. All models accept 24 VDC input and include a swivel rod end and adjustable tube mount for flexible mounting.

How to Order

Order by model number with the appropriate stroke length and load capacity. For accompanying control selection, see page 18.

Stroke Length	Model Number 500 lb. capacity	Model Number 1000 lb. capacity
4"	P24-05B5-04RD	P24-20B5-04RD
8"	P24-05B5-08RD	P24-20B5-08RD
12"	P24-05B5-12RD	P24-20B5-12RD
18"	P24-05B5-18RD	P24-20B5-18RD
24"	P24-05B5-24RD	P24-20B5-24RD

FIGURE 4.10



ROLL MOTION SCHEMATIC

FIGURE 4.11

ROLL MOTION

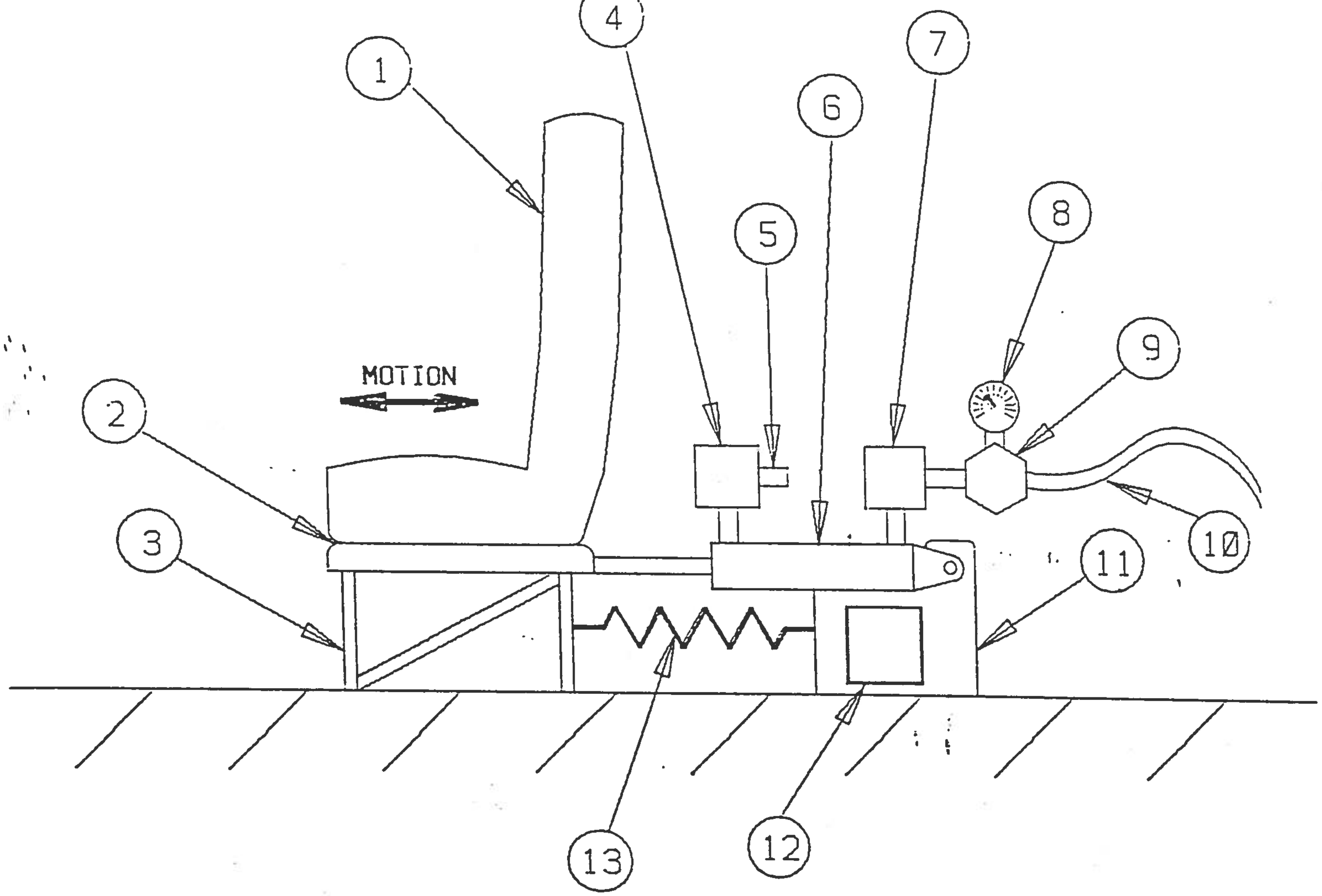
1. Main Tube
2. Roll Bearing
3. Tie Bar
4. Tilt Pivot
5. Linear Actuator
5. Actuator Upper Mount
7. Actuator Lower Mount

FIGURE 4.12

not repeatable. In addition, the system sent large electrical transients through the whole electronic system which created other electronic problems. The final design was changed to an air driven cylinder operated by electrically operated solenoids. This system works off a basic pressure of 90 psi. The solenoid valves operate directly from computer control to give the air cylinder the proper stroke length and direction. This system proved to be the simplest and most workable. (Refer Figures 4.8 and 4.9)

4.7 CAB ROLL SYSTEM

The roll system originally utilized a 12 volt linear actuator manufactured by Warner. When this system was installed, we found out that if there was a large proportional difference between the weight of the operator and the weight of the driver, the system would not respond as required due to overload. The actuator was replaced with a 24 volt actuator (recirculating ball electrac-100) driven by two 12 volt batteries in series. (Refer Figure 4.10, 4.11 and 4.12) The electrical circuit is a standard switching circuit controlled by Motorola 6805 microprocessor. This microprocessor and driven circuit are mounted together in the motion control system. The motion control system is driven



SEAT MOTION SCHEMATIC

SEAT MOTION

1. Seat
2. Seat Slider
3. Seat Support
4. Exhaust Solenoid Valve
5. Exhaust Muffler
6. Air Cylinder
7. Inlet Solenoid Valve
8. Pressure Gage
9. Air Pressure Regulator
10. Inlet Air Line
11. Support Bracket
12. Electronics
13. Return Spring

FIGURE 4.14

directly by the main processor, the Motorola 68ØØ. The seat motion is pneumatically driven fore and aft. The seat uses the same shop air at 9Ø psi as the pitch system. The seat is driven forward to simulate deceleration under braking conditions. The air cylinder is controlled by a Asco electrical solenoid which, in turn, is controlled by the main computer. The seat is returned by a spring. (Refer Figure 4.13 and 4.14)

5.Ø MODEL SYSTEM

5.1 INTRODUCTION

a) The model system consists of four different sections. The are the models of buildings, aircraft and vehicles as normally seen on an air base.

b) The smoke and wind system which are designed to operate as a unit to obtain the realism required.

c) The fire system which required a major design change.

d) The modelboard itself.

These systems required a great deal of engineering during the development program to obtain the necessary realism required of a full system.

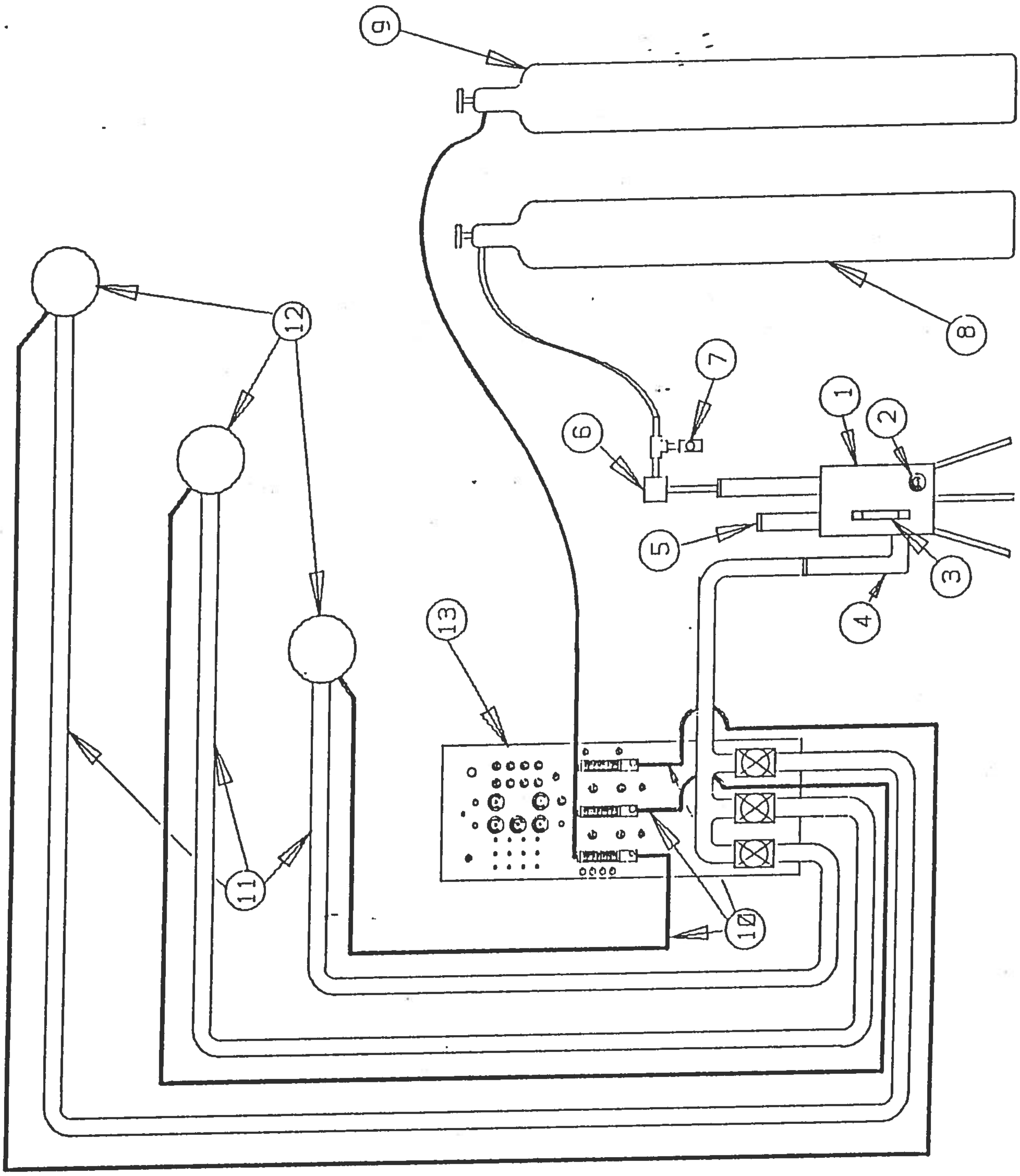
5.2 THE MODEL SYSTEM

The model system for this Simulator was originally intended to be scale models constructed of wood and other materials to be replicas of standard Air Force buildings. The vehicles were to be models (commercially available) of normal vehicles found on an air base. On initial testing it was determined that the actual models would not have the realism for the close-up camera work that would be available through the high resolution camera system. The original plan and models were scraped. It was then decided to use a photography technique that requires a photograph of the four sides of a building. This photograph is then modified to an 8Ø to 1 scale of the actual size of the building. A model of the building is manufactured just using wood for the frame. The photographs are attached to the four sides and when this building is observed through the probe system, it gives a very lifelike appearance. This was the technique which was accepted and proven to be the most realistic for this type of Simulator. The vehicle models were actual models purchased from high quality model makers and these vehicles included crash vehicles as well as private and military vehicles. The aircraft, such as the B-42 and C-130 were purchased model systems that were constructed and then configured as necessary as a crashed aircraft and placed over one of the three fire pits. These models can be interchanged as required by the instructor to insure that the training does not get too repetitive. The models thus turned out to be cost effective and realistic.

5.3 SMOKE AND WIND SYSTEM

The original smoke system utilized a Rosco system which is a commercially available device used in most theaters for producing stage smoke. They normally infringe a hot plate with a glycol solution that vaporizes it and produces a milky white smoke. The problem that arose with this system is that from the time it was pumped from the smoke generator out to the fire pits, it cooled off considerably thus the cool smoke would not rise but simply hung close to the ground. In addition, the glycol would cling to the various surfaces and leave an oily deposit on the models. The next experiment with titanium tetrachloride which produced large amounts of fast rising smoke when the powder was exposed to a humid atmosphere. Upon investigation we found this chemical could possibly have some toxic side effects and would be dangerous to work with in the quantities required in an ongoing training system. This design was eliminated.

The third system designed and subsequently manufactured proved to be simple, effective and non toxic. A heater pot, one foot in diameter by two feet with two commercial immergence heaters set in it. This pot is initially filled with about four inches of water which is kept at a temperature of 140 degrees Fahrenheit to 160 degrees Fahrenheit by two immersion heaters. Liquid CO_2 is sprayed on the hot water and it instantly turns to a grayish white smoke. This smoke is pumped out via the instructor's control valves to any of the three fire pits. At this time the instructor adds helium to the smoke such that when the helium and CO_2 arrives at the designated fire pit, the gas will rise as if it was burning. The wind systems are 115 volt AC squirrel cage fans attached under the modelboard. They expell the air up through a hole in the modelboard. The top of the modelboard, at that point, has a "U" shaped bracket that only allows the air to proceed in a horizontal direction. The moving air is set so that it blows towards the fire pits. The wind "On"



SMOKE SYSTEM SCHEMATIC

FIGURE 5.1

SMOKE SYSTEM

1. Smoke Generator
2. Water Heater
3. Water Level Sight Glass
4. Smoke Outlet
5. Water Filler
6. CO_2 Solenoid Valve
7. Bleed Valve
8. CO_2 Bottle (Siphon Tap)
9. Helium Bottle
10. Helium Lines
11. Smoke Pipes
12. Fire Pits
13. Instructor's Console

FIGURE 5.2

and "Off" is controllable by the instructor.

The CO_2 requirement is 3 pounds per minute, the helium is 1 CFM. (Refer Figure 5.1 and 5.2)

5.4 FIRE SYSTEM

The fire system proposed and originally manufactured utlized SCR controlled incandescent lamps that were controlled by a white noise generator to give a flicker effect, thus, as the lights are flashed on and off in a random pattern, the beams would be displayed on the rising smoke which gives the simulation of a fire. Using this technology and also steady state orange type lights impinging directly upon the rising smoke gave a poor simulation of an actual crash fire. This system was rejected and another system was developed that simulated a burning aircraft at each of the fire pits as required. (Refer Figure 5.3 and 5.4) The DC motor which operates on 12 volts at 4 amps is a VonWeise VA93. It drives the flame colored lenses assembly directly. As these lenses rotate they pass and then cut off each of the 4 flame lights. The flame lights are standard 12 volt 50 watt Westinghouse Quartz Halogen Bayonnet Bulbs. The lenses are alter

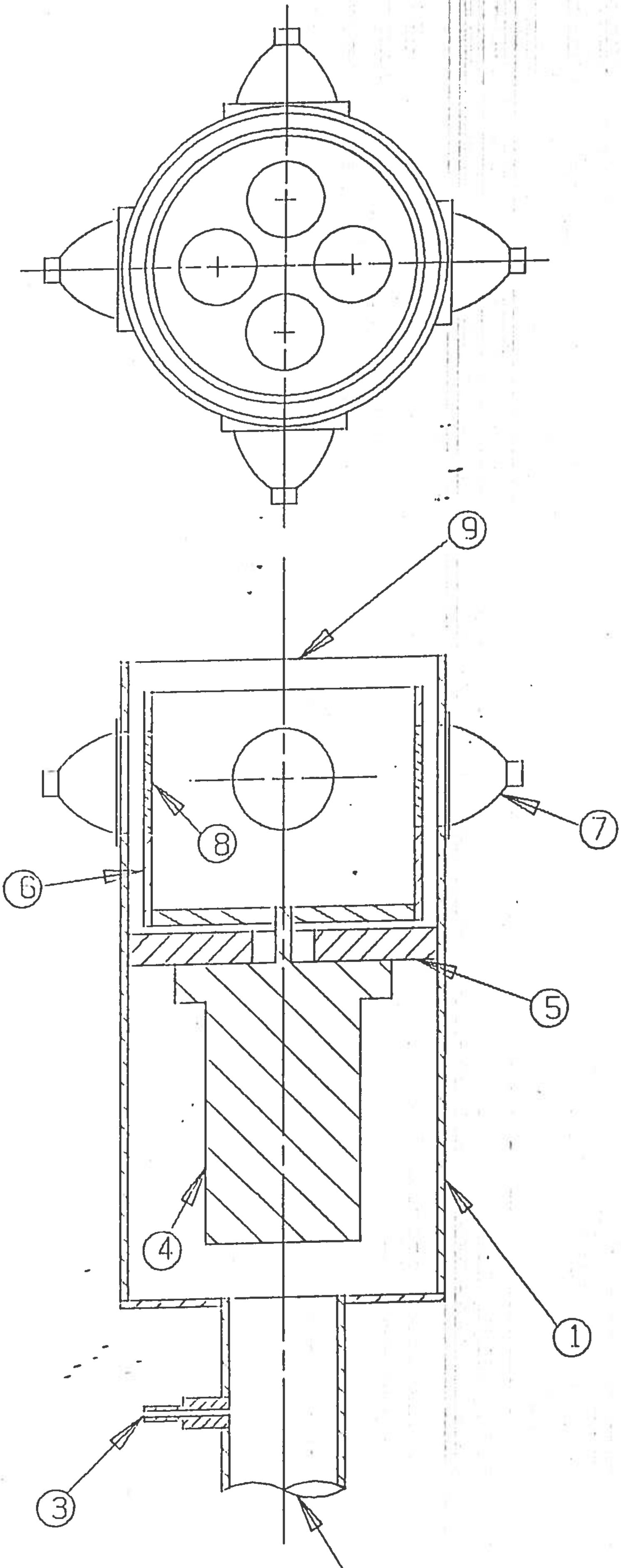


FIGURE 5.3

SMOKE AND FIRE PIT

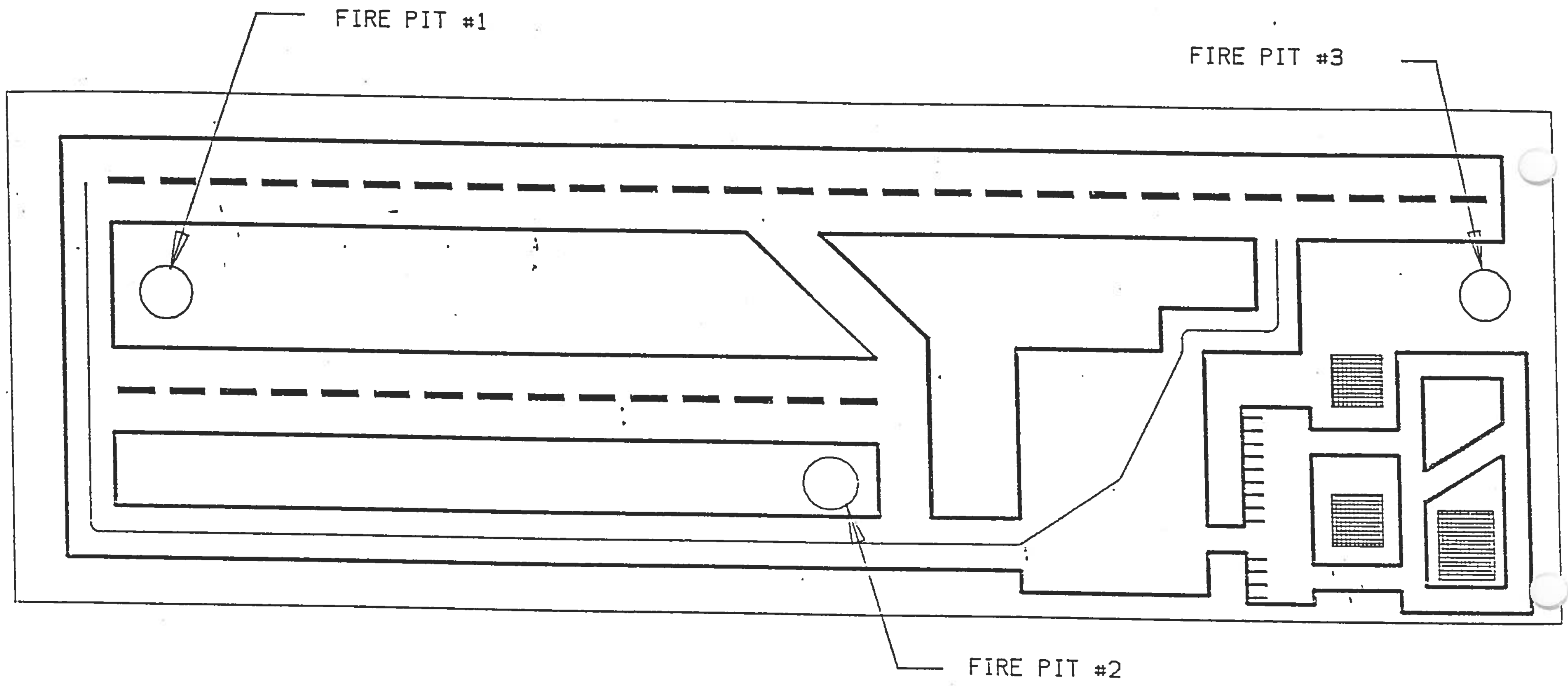
1. Smoke and Fire Pit
2. Smoke Inlet
3. Helium Inlet
4. Flame Flicker Motor
5. Motor Support Bar
6. Flame Flicker Drum
7. Flame Light
8. Flame Colored Lens
9. Smoke and Flame Outlet

FIGURE 5.4

nate amber and red. This flashing light impinging upon the rising smoke gives an excellent simulation.

5.5 MODELBOARD

The modelboard is constructed of multi-sheets of outdoor grade 1 inch thick plywood. The plywood was finished on both sides and the sheets were 4 foot by 10 feet. The plywood was bolted to the flat base of the gantry (shimmed where necessary) and leveled with a surveyors transit. When all the sheets were flat, the joints were sealed with epoxy. The modelboard presented is one large flat surface. The board was then painted using a standard industrial paint to the outline shown in Figure 5.5. The runway lights were installed by using miniature bulbs inserted from the bottom with just the tip of the bulb protruding less than 1/16 of an inch above the modelboard. Additional trees and shrubs were installed to give a more realistic appearance.



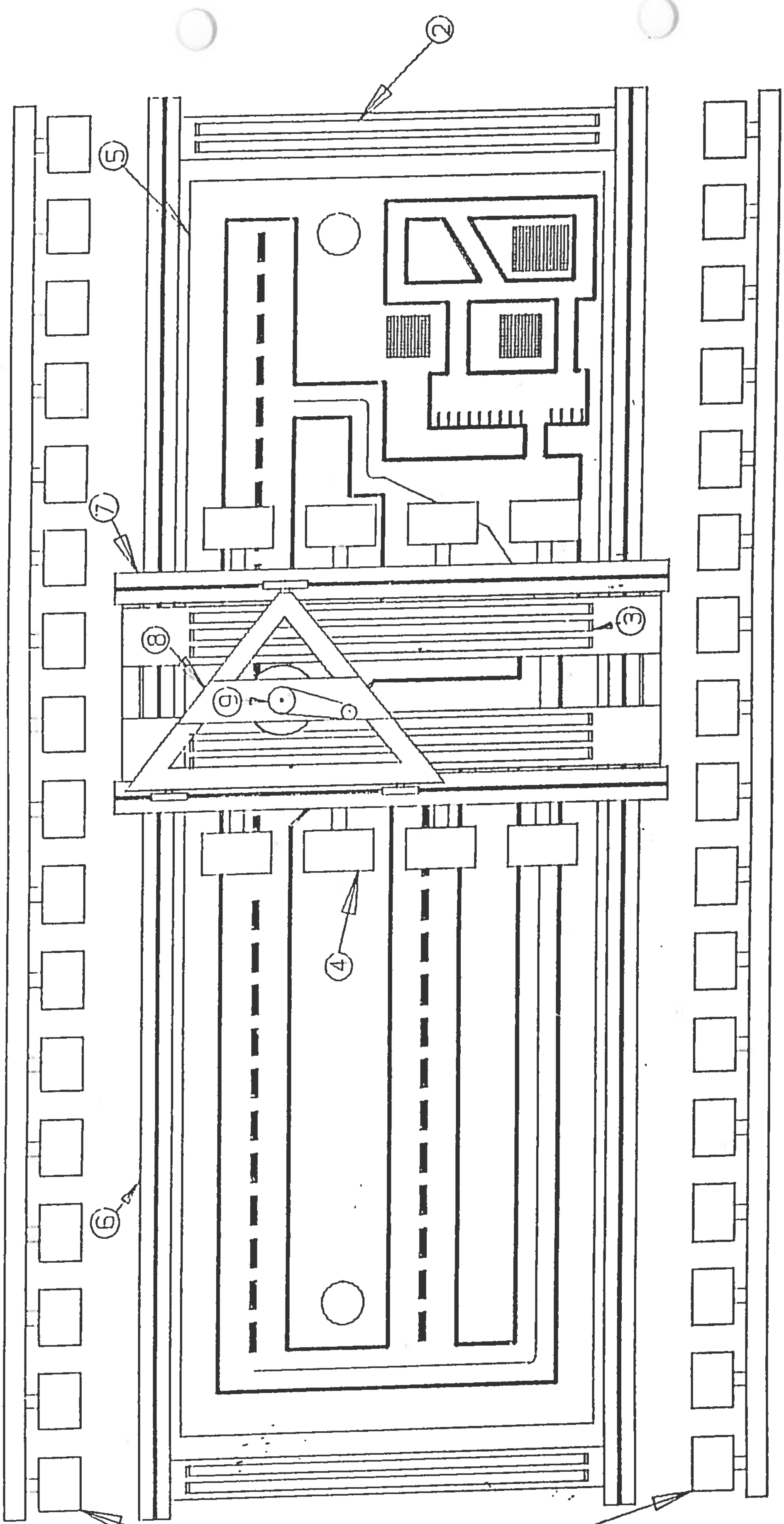
MODEL BOARD SCHEMATIC

FIGURE 5.5

6.Ø GANTRY SYSTEM

6.1 INTRODUCTION

The main frame ("X" axsis) was designed and made of heavy duty steel "I" beams. The movable gantry ("Y" axsis rides on the main frame, and is manufactured of aluminum. The rotational probe system ("Z" axsis) is made of stainless steel and aluminum. All of these components were designed and manufactured in house. There are no problems with the frameworks themselves, however, there was some vibration in the "X" drive system due to some inherent instability in the long drive shaft. These problems were resolved and the gantry proved to be an extremely effective and stable platform for the optical probe system. (Refer Figures 6.1 and 6.2) There are three drive motors on this system, one for the "X" axsis (parallel to runways), the "Y" axsis (the short direction) and the "Z" axsis (the rotational axsis). The drive motors and amplifier selected are Inland Motor DA servos with integral tachometer generator (Refer Figures 6.3, 6.4 and 6.5) These motors proved to be exceptionally stable and had a turn down ratio (high speed to low speed ratio) of 1Ø,ØØØ



GANTRY SCHEMATIC

GANTRY SCHEMATIC

1. Main Lights
2. Sky Light
3. Moving Florescent Lights
4. Moving Quartz Lights
5. Model Board
6. X Track
7. X Gantry
8. Y Gantry
9. Azimuth

FIGURE 6.2

GENERAL DESCRIPTION

The TT-295X family of DC servo motor - DC tachometer generator units (herein called motor and tachometer) has been designed to meet exacting requirements. The design basics include permanent magnet field assemblies, low inertia, high continuous and peak torques, Class F insulation, and totally enclosed nonventilated construction.

INSTALLATION

I. Location

The unit should be placed where the ambient temperature will not exceed 40° C (104° F).

II. Mounting

The unit can be mounted in any position. The outline and assembly drawings for the unit depict all necessary mounting dimensions and wiring detail.

III. Terminal Box

An external terminal (or conduit) box, that may be rotated 180° for mounting convenience, is provided for lead connection. The motor leads (green and orange), thermostat leads (white), and the tachometer leads (black and white) are located in this box.

MAINTENANCE

I. General Maintenance Requirement

Normal DC motor maintenance procedures shall be used with the TT-295X family of servo drive motor tachometers. The motors use cartridge brushes

FIGURE 6.3

accessible from periphery of tach end bell. The tachometer uses a one-piece molded brush ring assembly. The bearings are sealed and permanently lubricated.

The permanent magnet field assemblies do not require maintenance. Armatures, both tachometer and motor (when necessary), can be removed from their field assemblies without the use of keepers with no loss of sensitivity. This disassembly is described in detail under Disassembly (Section III, Parts B and C).

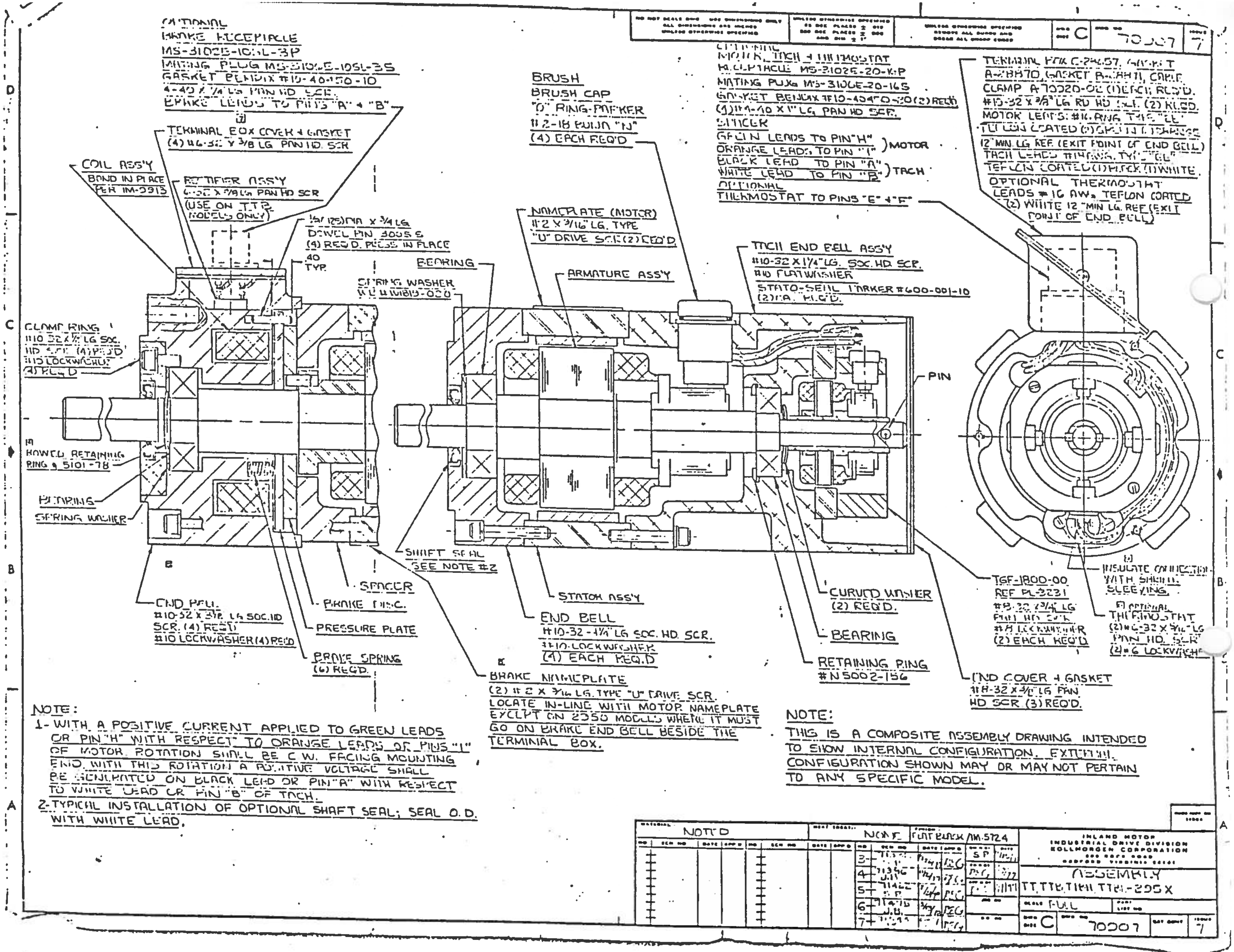

OPTIONAL
BRAKE RECEPTACLE
MS-3102B-10SL-3P
MATING PLUG MS-3106E-10SL-3S
GASKET BENDIX #10-40450-10
4-40 X 1/4 LG PAN HD SCR.
BRAKE LEADS TO PINS "A" & "B"
TERMINAL BOX COVER & GASKET
(4) #6-32 X 3/8 LG PAN HD SCR
COIL ASS'Y
BOND IN PLACE
PER IM-5913
RECTIFIER ASS'Y
(USE ON T.T.B. MODELS ONLY)
1/8 (.125) DIA X 3/4 LG
DOWEL PIN 3005 S
(4) REQ'D. PRESS IN PLACE
.40 TYP.
BEARING
SPRING WASHER
CLAMP RING
#10-32 X 1/2 LG SOC.
HD SCR (4) REQ'D
#10 LOCKWASHER
(4) REQ'D
BOWED RETAINING
RING # 5101-78
BEARING
SPRING WASHER
END BELL
#10-32 X 3/4 LG SOC. HD
SCR. (4) REQ'D
#10 LOCKWASHER (4) REQ'D
BRAKE DISC.
PRESSURE PLATE
BRAKE SPRING
(6) REQ'D.
SPACER
SHAFT SEAL
SEE NOTE #2
BRUSH
BRUSH CAP
"O" RING-PARKER
#2-18 BUNA "N"
(4) EACH REQ'D
NAMEPLATE (MOTOR)
#2 X 3/16 LG. TYPE
"U" DRIVE SCR (2) REQ'D
ARMATURE ASS'Y
STATOR ASS'Y
END BELL
#10-32 - 1 1/4 LG SOC. HD. SCR.
#10 LOCKWASHER
(4) EACH REQ'D
BRAKE NAMEPLATE
(2) #2 X 3/16 LG. TYPE "U" DRIVE SCR.
LOCATE IN-LINE WITH MOTOR NAMEPLATE
EXCEPT ON 2550 MODELS WHERE IT MUST
GO ON BRAKE END BELL BESIDE THE
TERMINAL BOX.
MOTOR, TACH & THERMOSTAT
RECEPTACLE MS-3102E-20-16P
MATING PLUG MS-3106E-20-16S
GASKET BENDIX #10-404020-20 (2) REQ'D
(4) #4-40 X 1" LG. PAN HD SCR.
SPACER
GREEN LEADS TO PIN "H"
ORANGE LEADS TO PIN "I") MOTOR
BLACK LEAD TO PIN "A"
WHITE LEAD TO PIN "B") TACH
OPTIONAL
THERMOSTAT TO PINS "E" & "F"
TACH END BELL ASS'Y
#10-32 X 1 1/4 LG. SOC. HD SCR.
#10 FLATWASHER
STATO-SEAL PARKER #600-001-10
(2) EA. REQ'D.
PIN
CURVED WASHER
(2) REQ'D.
BEARING
RETAINING RING
N 5002-156
TGF-1800-00
REF PL-3231
END COVER & GASKET
#8-32 X 3/8 LG PAN
HD SCR (3) REQ'D.
INSULATE CONNECTION
WITH SHRINK
SLEEVING
OPTIONAL
THERMOSTAT
(2) #6-32 X 3/16 LG
PAN HD. SCR.
(2) #6 LOCKWASHER
TERMINAL BOX C-24657, GASKET
A-28870, GASKET R-28811, CABLE
CLAMP A-70020-02 (1) EACH REQ'D.
#10-32 X 3/8 LG RD HD SCR. (2) REQ'D.
MOTOR LEADS: #16 AWG TYPE "EE"
TEFLON COATED (2) GREEN (2) ORANGE
12" MIN LG REF (EXIT POINT OF END BELL)
TACH LEADS #18 AWG TYPE "EE"
TEFLON COATED (1) BLACK (1) WHITE
OPTIONAL THERMOSTAT
LEADS #16 AWG TEFLON COATED
(2) WHITE 12" MIN LG. REF (EXIT
POINT OF END BELL)
NOTE:
1- WITH A POSITIVE CURRENT APPLIED TO GREEN LEADS OR PIN "H" WITH RESPECT TO ORANGE LEADS OR PINS "I" OF MOTOR ROTATION SHALL BE C.W. FACING MOUNTING END. WITH THIS ROTATION A POSITIVE VOLTAGE SHALL BE GENERATED ON BLACK LEAD OR PIN "A" WITH RESPECT TO WHITE LEAD OR PIN "B" OF TACH.
2- TYPICAL INSTALLATION OF OPTIONAL SHAFT SEAL; SEAL O.D. WITH WHITE LEAD.
NOTE:
THIS IS A COMPOSITE ASSEMBLY DRAWING INTENDED TO SHOW INTERNAL CONFIGURATION. EXTERNAL CONFIGURATION SHOWN MAY OR MAY NOT PERTAIN TO ANY SPECIFIC MODEL.
NOTED
NONE
FLAT BLACK /IM-5724
INLAND MOTOR
INDUSTRIAL DRIVE DIVISION
KOLLMORGEN CORPORATION
ASSEMBLY
TT, TTB, TTM, TTM-295X
FULL
C
70007
7

FIGURE 6.5

to 1. The motor inputs were determined by the driving algorithm and these inputs varied from 1 millivolt to 1Ø volts DC in all three axsis. The inputs to the drive motor amphlifier came directly from the D/A section of the microprocessor. The wires were shielded and properly grounded to eliminate any extraneous noise pick up. These drive systems exceeded all the requirements for the motion of the probe.

6.2 GANTRY MOTION

It was decided at an early stage that standard servo motors and controllers should be used in the gantry motion system. This was done in order to enhance the maintainability of the system.

The servo and controllers response characteristics had to be matched to the inertial loadings of the modelboard gantry assembly to achieve a stable and acceptable motion profile.

The calculated inertias in the "X" axes reflected at the servo motor shaft were higher than for the "Y" or the "Z" axsis and therefore dominant.

They were:

GANTRY	:	3.1 x 1Ø	lb. ft. S
ALL ROTATING COMPONENTS	:	1.48 x 1Ø	lb. ft. S
TOTAL GANTRY	:	4.58 x 1Ø	lb. ft. S

The servo motor finally chosen was an Inland Motors TT 295Ø, having the following characteristics:

MAX TORQUE	:	12 ft. lb.
MAX ACCELERATION RATE	:	17ØØØ RAD/S
ROTOR INERTIA	:	Ø.695 x 1Ø lb. ft. S

This gave a gantry/motor inertia ratio of 6.6. This ratio was acceptable for good response characteristics within the driving envelope which called for 722 RPM at 6Ø mph equivalent speed. This equivalent modelboard speed was 1.2 ft./sec.

The Inland Motor controller chosen was a single card type, model No. SB1-160/10 PWM. It possessed the following characteristics:

FEED BACK LOOPS	: Proportional, differential, integral and current.
INPUT SIGNAL	: IO - 10 VDC
RESOLUTION	: 1 MV
RATED CURRENT CAPACITY	: 20 A
TURNED RESPONSE AT RATING	: One overshoot, one undershoot.

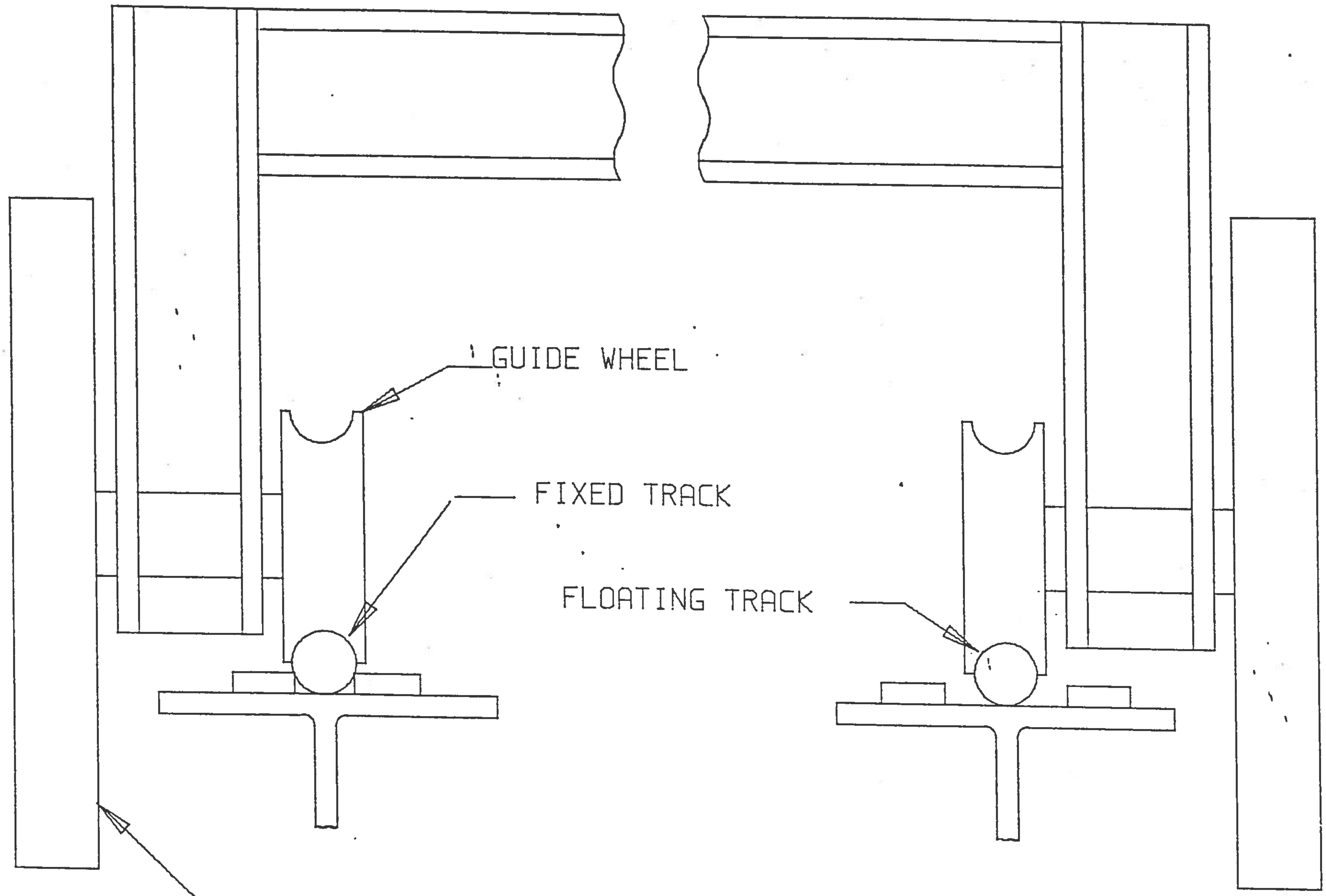
Azimuth Control System Problem

A resonance was experienced in the azimuth subsystem, which disabled the control system. The resonance frequency was in the low ultrasonic range. The system inertia was changed by substituting the drive gear with another of different polar inertia that corrected the problem.

6.3 "X" AXES FRAME

The axes frame consists of two 12 feet x 4 feet steel "I" beams) that are separated and bolted together by 8 feet by 4 feet steel "I" beams. The unit was bolted together to make it possible to be moved from site to site after manufacture. This whole framework is mounted on steel legs with screw adjustments on the bottom to insure proper alignment on the top of the 12 inch by 4 inch steel "I" beams. There is a 3/4 inch seamless stainless steel shaft that acts as the rails for the top gantry. (Refer Figure 6.6) On one side this 3/4 inch steel shaft is firmly attached to the top "I" beam. On the other side it is mounted between two small bars that allows it to move in the "Y" direction. Thus if there is any thermal expansion problems, this rod has the ability to move freely to adjust for slight differences in the width of either the main frame or the "Y" gantry.

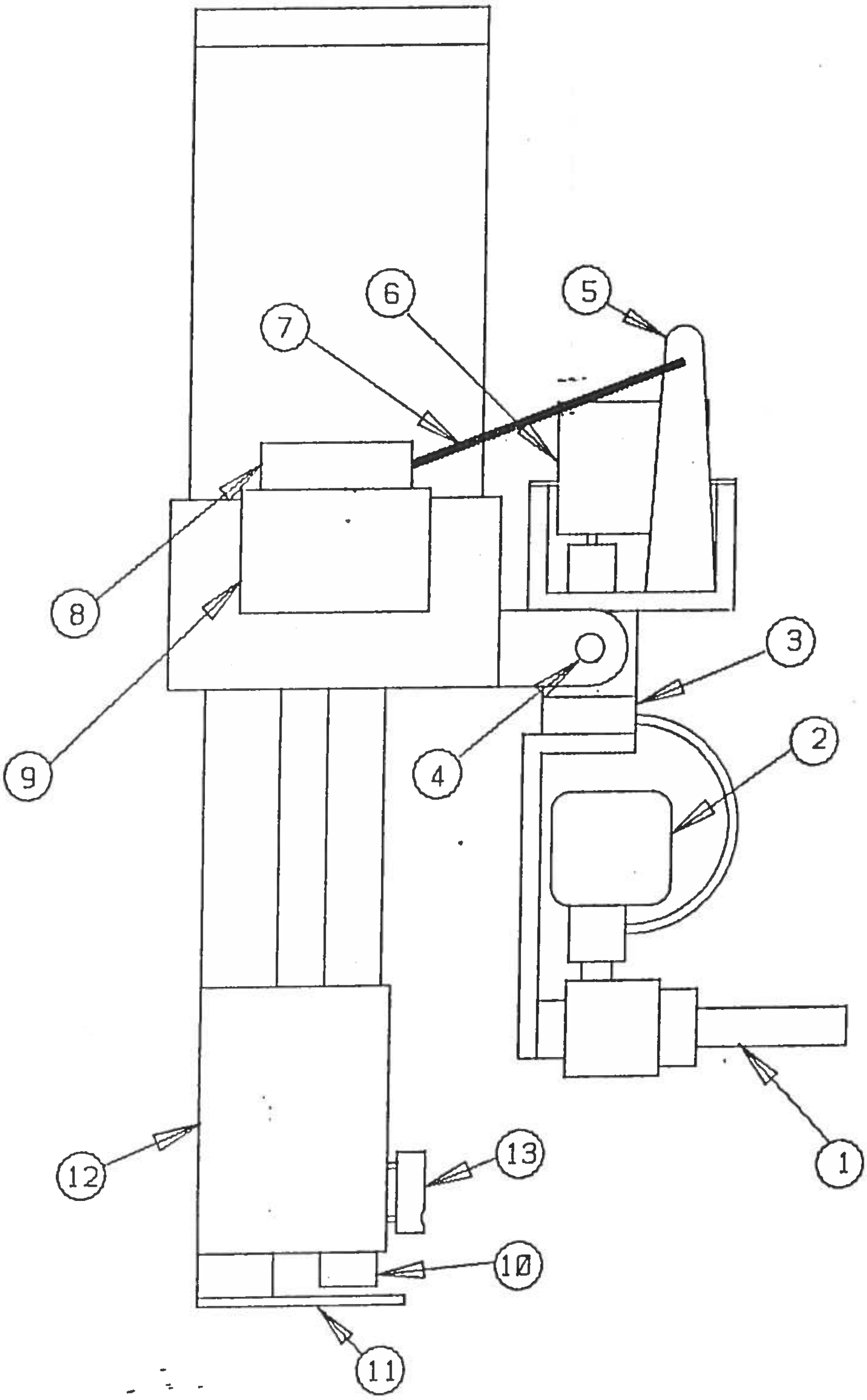
The "Y" gantry is constructed of 6Ø61 T6 rectangular structural aluminum. This was to minimize the inertia problems and lessen the load on the servo systems. The "Y" gantry rolls on four ball bearings wheels with concave groves that fit directly on the 3/4 inch stainless steel rod of the "X" axes. Two of the wheels, one on either side are driven by two



FLOATING TRACK SYSTEM

belts from the main drive motor. This main drive motor is connected to a drive shaft that spans the "Y" gantry. As originally designed there was excessive vibration (whipping) in this drive shaft under high speed operation. A shaft of larger diameter would normally be the solution. However, this would increase the polar inertia of the shaft adversely affecting the response characteristics of the servo. The final solution was the use of a 1/2 inch diameter shaft concentric to a fixed 3 inch support tube and attached to it at three places by internal ball bearings.

The "Z" axsis are rotational axsis, constructed of aluminum and stainless steel for both weight and strength requirements. This system was designed to be a multi rotational device but since it was designed without slip rings, it is necessary to limit the rotation to a full seven turns. Thus, starting at the midpoint, the vehicle can make 3 each, 360 degree turns before the vehicle must be turned in the opposite direction. With the layout of the modelboard and the scenarios, as submitted, there are no problems with hitting the limit switches. All the electrical inputs to this system were designed so there would be enough slack so that they could wrap around the "Z" ax-



LOWER PROBE ASSEMBLY

FIGURE 6.7

LOWER PROBE ASSEMBLY

1. Foam Nozzle
2. Foam Valve
3. Rotating Foam Union
4. Tilt Assembly
5. Tilt Control Arm
6. Rotation Servo
7. Tilt Connecting Rod
8. Tilt Servo
9. Servo Receiver
10. Lens Assembly
11. Lower Optics Shield
12. Upper Optics Shield
13. Headlight

FIGURE 6.8

sis without any interference. The liquid CO_2 system which consists of a heavy duty neoprene hose required a pulley and weight system to compensate for any slack in the hose system as the probe rotated. (Refer Figure 6.7 and 6.8)

7.0 OPTICS SYSTEM

7.1 OPTIC SYSTEM INTRODUCTION

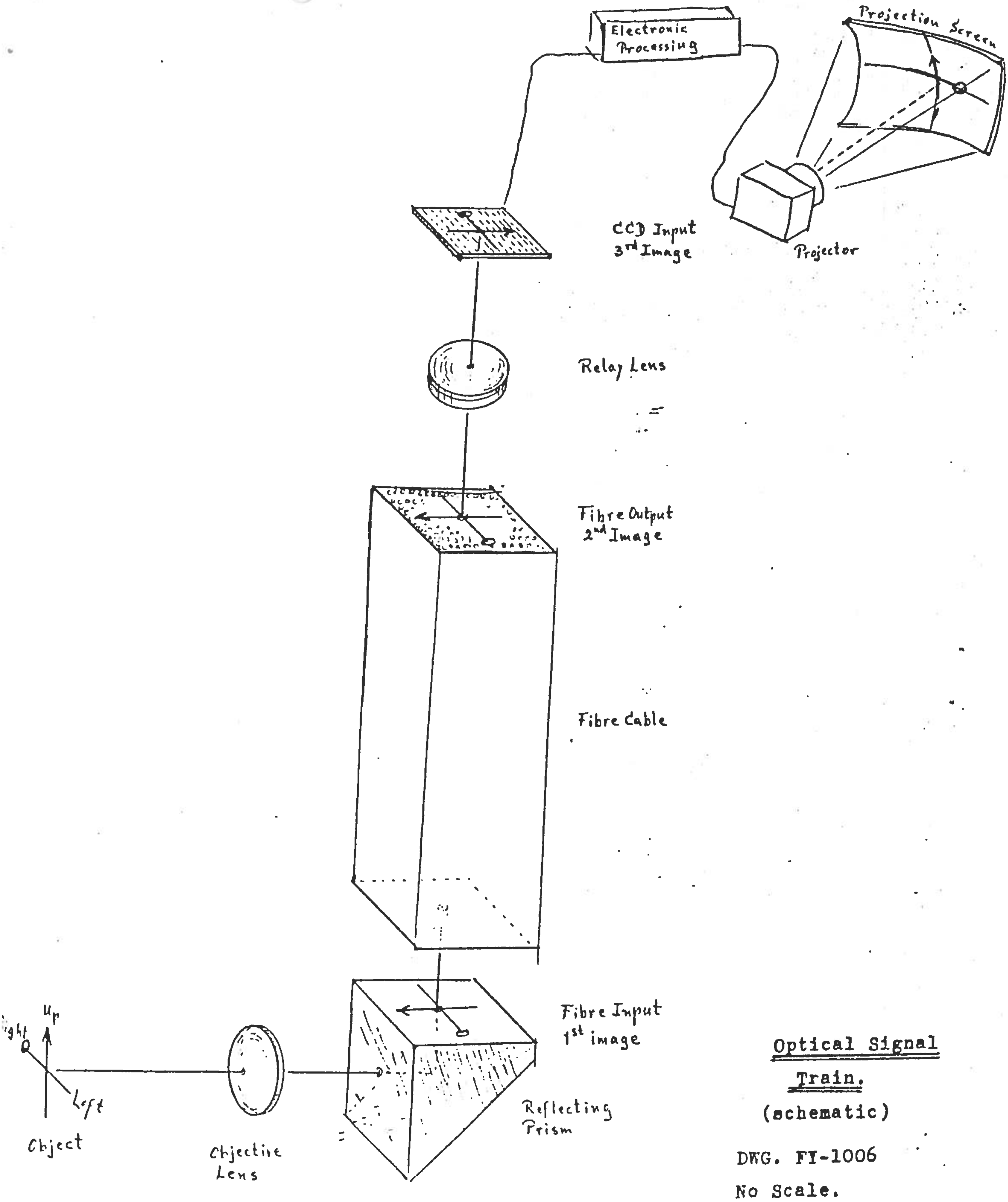
The optical system is one of the more complex sections of the system. It took the longest amount of time to design and build. A number of problems with the optics was that a small probe as is possible was required, as well as a complete wrap around field of view and good resolution. The probe design was initially a six lense system with the optical view being transmitted up six separate tubes through sets of lenses set at critical points. These lenses relay the view information from one lense to another until it is displayed in front of a camera that will pick it up and make it available for display. There were problems with this design and it was changed over to a five lense system with the video image being transmitted up five separate fiber optic bundles. With these bundles terminating in front of each their respective cameras, this caused a major time problem in the design and manufacturing of the simulator.

7.2 ORIGINAL DESIGN

The original designs major problems was the critical positioning of each of the relay lenses. It was possible in a laboratory set up to build a lensing system and adjust it for correct operation. However, if there was any motion of the system that was not of a gentle nature, the lenses could shift and the whole system would be out of focus. This system could not be preset and locked in as a factory manufactured part as adjustments would always be necessary in the field. This problem coupled with the fact that there was six separate lensing system and each one had to be individually adjusted if there was excessive motion in the relay system. This motion could be as simple as a driver making a mistake and driving the optic probe by accident into one of the models. It was thus quite probable that the instructor/operator would spend a great deal of time readjusting all these lenses. Even though it was proven that the system was technically feasible and would meet the systems requirements, the reliability would not have been acceptable. So this design was dropped.

7.3 FIBER OPTIC SYSTEM

The fiber optic system reference Figure 7.1 system schematic shows the basic layout of the system. There is one objective lense that is adjustable at the front of the probe. This focuses the information on to the reflecting prism which translates it through the fiber cable to a single relay lense which is then picked up by the CCD Camera input and transmitted via the camera to the projector. Figure 7.2 shows the layout of the optical image plane. Showing the video input into the five channels and their angular displacement. Figure 7.3 is a schematic assembly of the fiber optic cable which is physically attached to the optical input plane. Figure 7.4 gives the relative position of the lense assembly. This complete assembly is encased in a sturdy structural housing that allows the system to be driven around the modelboard and occasionally be bumped into models without any excessive damage to the assembly. There is one problem with the fiber optic assembly and that is each of the five bundles consist of 680 X 680 of fiber optic tubes attached



Optical Signal Train.

(schematic)

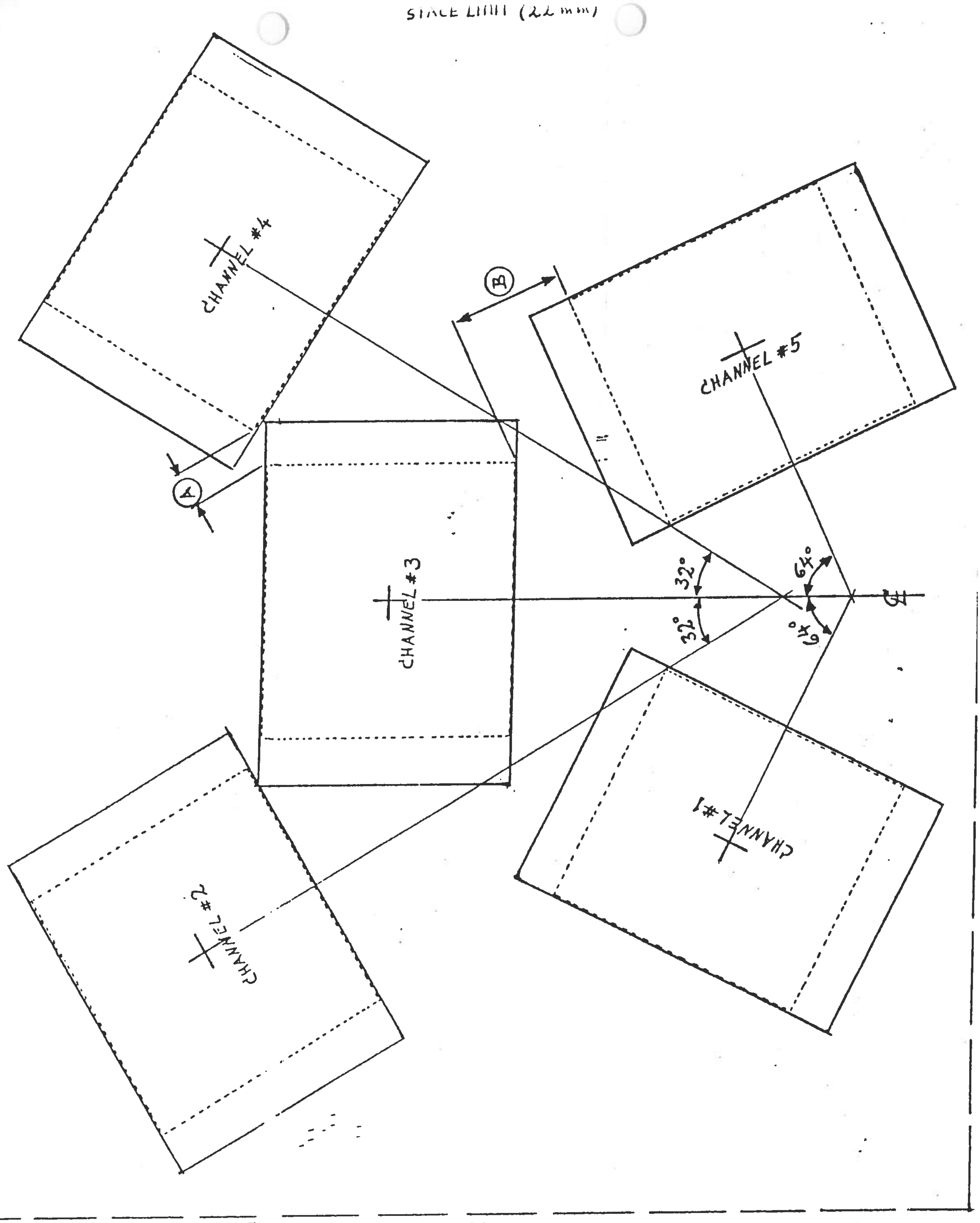
DWG. FI-1006

No Scale.

FIRE RESEARCH
26 SOUTHERN BLVD.
NESCONSET, NEW YORK 11767

MH85C4K

FIGURE 7.1

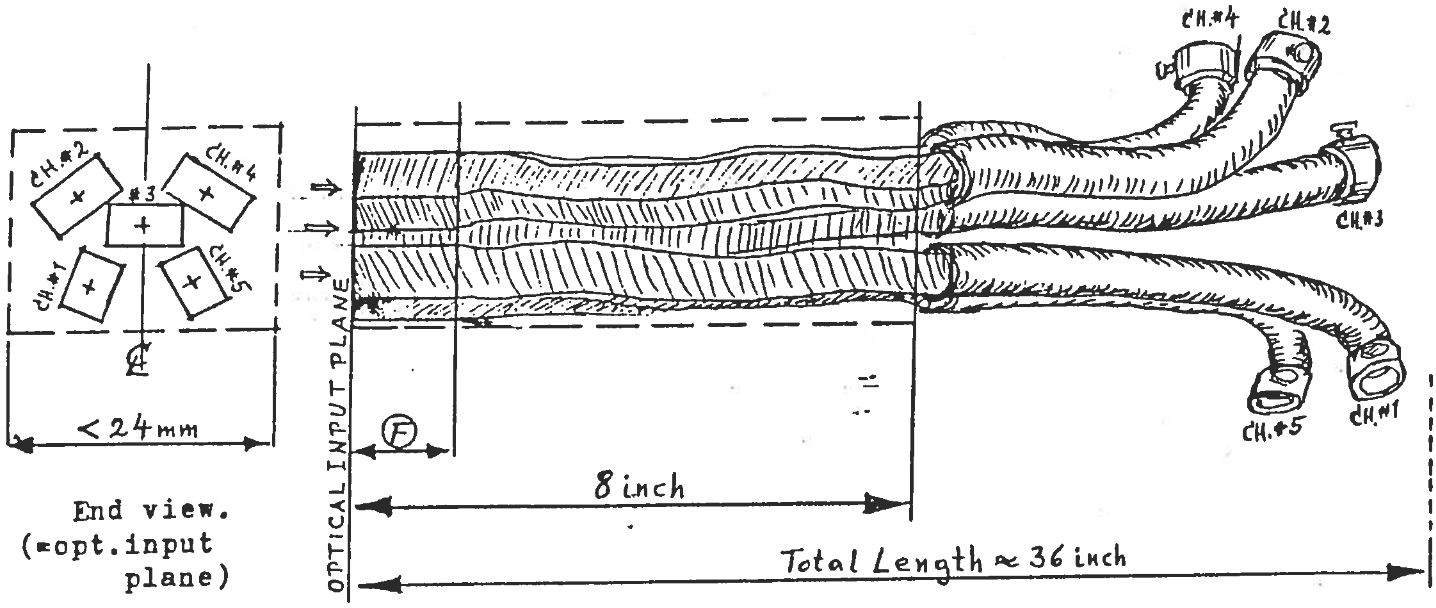


Dimensions (A) and (B) as small as possible.
.... = size of opt.image (5.00x5.40mm)
- - - = max.avail.cross sect.area up to cable length · 203 mm.

OPTICAL IMAGE PLANE.

DWG.FY-1005
Scale 10:1
R&M Res.Lab., Flushing, NY 11354
85.04.09

FIGURE 7.2



Fibre Cable Assembly (schematic).

----- = max.available space limitation
For details of input plane see DWG.FY-1005.

(F) = Front portion of cables at the optical input plane. This dimension may be designed from 1/4 up to 8 inch. depending on cable flexibility and holding structures. This front portion must be rigid,at least for each individual cable,if assembly consists of separate cables mechanically held together.

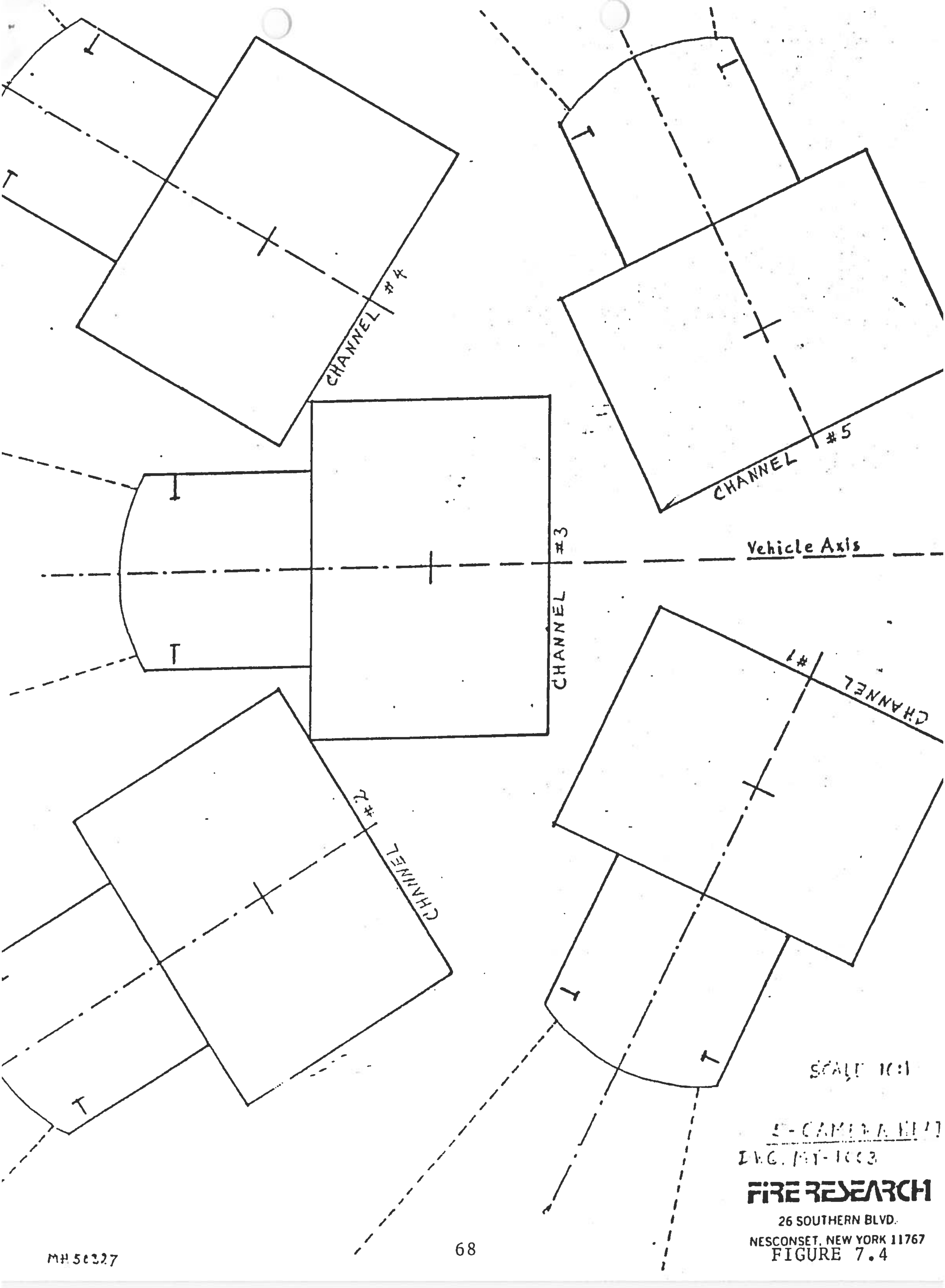
Assembly
Fibre Cables (schem.)

DWG. FY-1004

No Scale.

RAM Research Laboratory
Flushing, NY 11354

FIGURE 7.3



SCALE 10:1

5-CAMERA ...

DWG. MT-1003

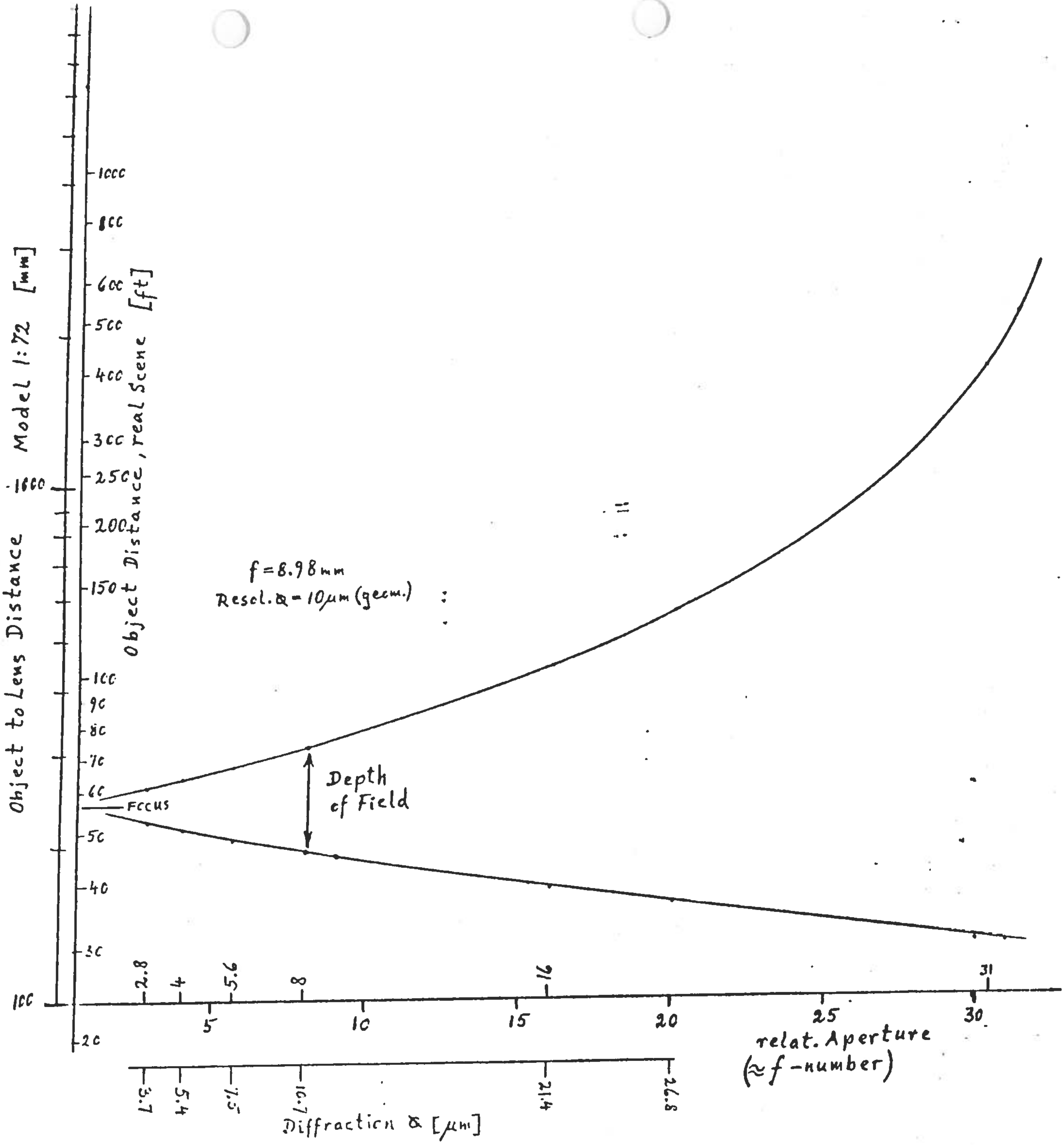
FIRE RESEARCH

26 SOUTHERN BLVD.

NESCONSET, NEW YORK 11767

FIGURE 7.4

MH 5e327

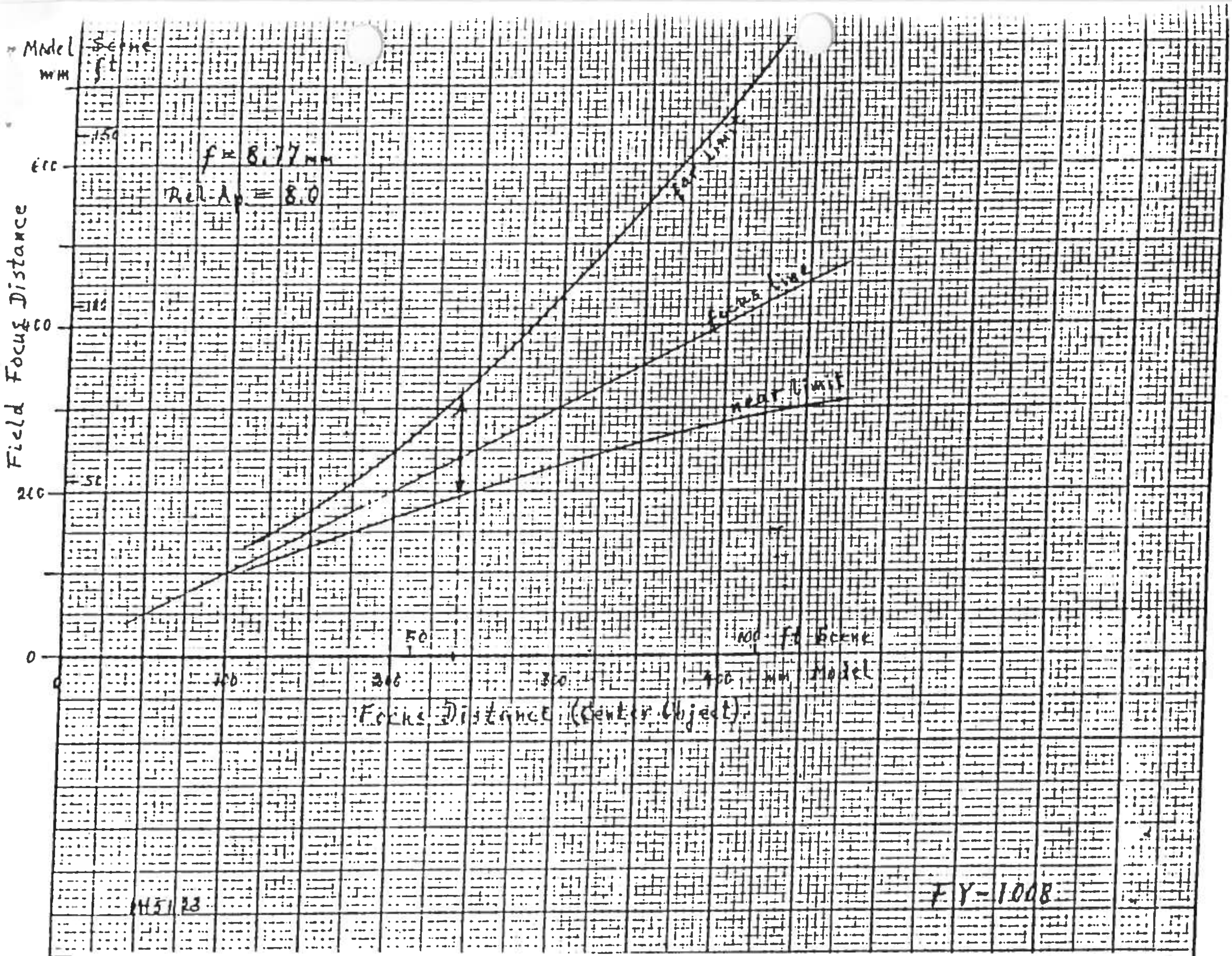


MH5 1123

FY-1007

FIRE RESEARCH
20 SOUTHERN BLVD
NESCONSET, NEW YORK 11767

FIGURE 7.5



FIVE CHANNEL FIBER OPTIC CABLE SPECIFICATIONS

GALILEO ELECTRO OPTICS

Fiber Diameter:	10 micron
Coherent Fiber Bundle:	6 X 6 fibers cemented together to a 60 micron X 60 micron square
Fiber Optic Cable:	Composed of edge cemented fiber bundles to an O.A. viewing area of 5 millimeter X 5.4 millimeter
Fiber Breakage:	0.5 percent maximum
Light Transmission:	25 percent at 440 nanometers, 45 percent at 700 nanometers
Resolution:	50 line parts per millimeter
Coherency:	0.001 inch maximum deviation
Surface Temperature:	-60 degrees Fahrenheit minimum +180 degrees Fahrenheit maximum

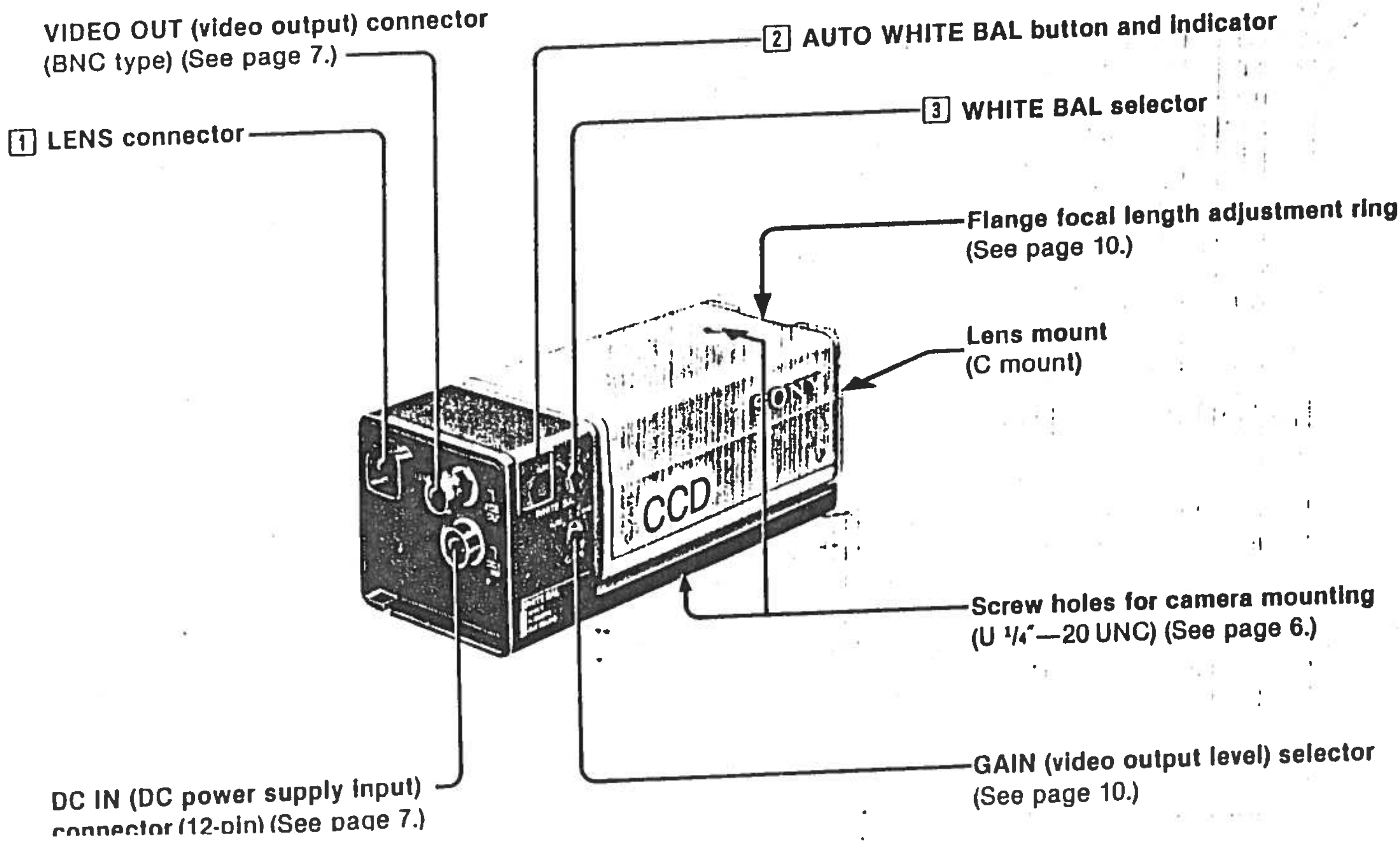
FIGURE 7.6

to each other in bundles of 6 X 6 (36 total) in such a manner that whatever is transmitted in one tube that will be projected at the exact same point at the end of the bundle. Unfortunately, in the manufacturing and assembly process some of the optic fibers break and this will be shown as a dark spot by the projector. It is possible, however, through careful manufacturing techniques and handling to build a system that will minimize the number of broken fibers. Figures 7.5 and 7.6 show the depth of field and the focus distance obtained with this design.

7.4 CAMERA SYSTEM

The camera selected for the final design is a Sony DXC-1Ø1/1Ø1P, reference Figure 7.7. This system was selected because of its very low light capability. This is inherent in any CCD Camera, but at the time of purchase this camera had the best capable of any in the market place. The cameras are mounted firmly to a round plate on the rotating part of the gantry system. This eliminates the need of any twisting of the fiber optic cables. Each of the fiber optic cables terminates at the input of the CCD Camera. As shown in Figure 7.7, the instructor has the capability to adjust the video gain for each of the

LOCATION AND FUNCTION OF PARTS



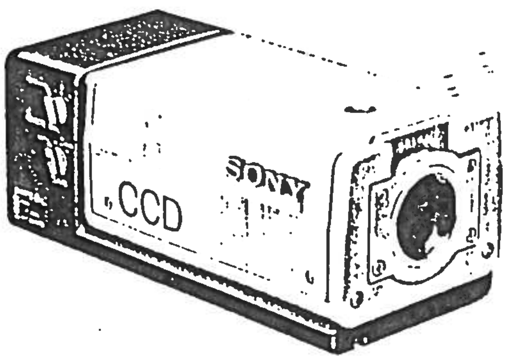
SONY

COLOR VIDEO CAMERA

DXC-101/101P

OPERATING INSTRUCTIONS

Before operating the unit, please read this manual thoroughly and retain it for future reference.



CCD

FIGURE 7.7

cameras. These cameras have proven to be both reliable and sturdy and will work well under the environmental conditions that the simulator will be subject to.

7.5 PROJECTORS

The projectors that were selected were the Aqua Star 3B manufactured by Electronic Systems Products in Titusville, Fl. These projectors were selected because of their high video output and their compact size. Two other types of projectors were studied but they did not have the compact size needed to fit under the cab of the vehicle without physically interfering with each other. The Aqua Star 3B is shown in Figure 7.8, the specifications on Figure 7.9, and the schematic on Figure 7.10.

7.6 SYSTEM LIGHTING

The lighting for this system was originally conceived to be series of fluorescent tubes mounted above the gantry of the modelboard. That would give sufficient lighting for the Sony Camera. After the system was manufactured and testing started, it was determined that the lighting was not bright enough. There was also a problem with shadows as the gantry

ESP®

ELECTRONIC SYSTEMS PRODUCTS

AQUASTAR IIIB

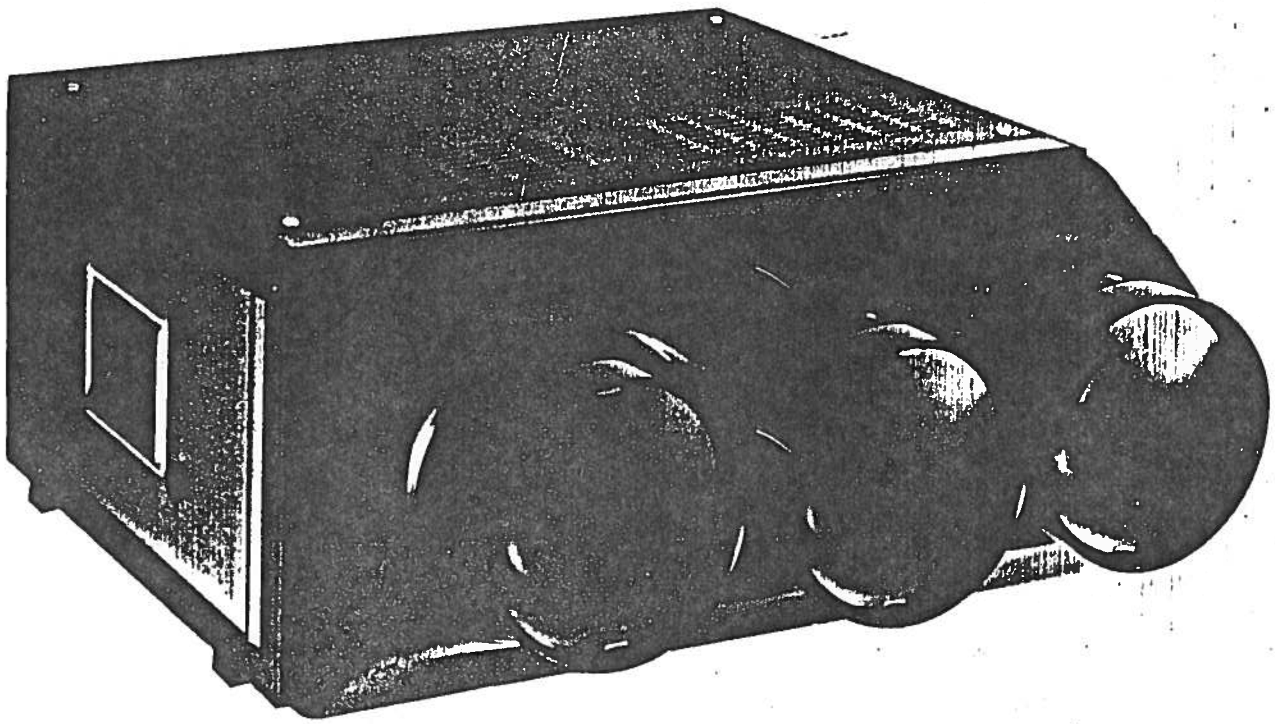


FIGURE 7.8

AQUASTAR III B

SPECIFICATIONS

Optical:	f:1 refractive with liquid field corrector
Throw Distance:	1.5 times screen width (i.e. 6' wide screen 9' away)
Light Output:	400 lumens peak white
Resolution:	600 lines RGB-330 NTSC video
Cathode Ray Tubes:	40 kV magnetically deflected and focused, non-browning, strontium-filled glass, liquid-cooled color phosphors, peak current 4 ma each tube
Electrical:	mains: 115 V 60 Hz (standard) 240 V 50 Hz (optional) power: 300-400 watts
Video:	1 V P-P negative composite sync NTSC, RGB inputs with separate sync or sync on green, RGB gain controls, sweep: 525-625 line scan 50-60 Hz; PAL, SECAM and modified NTSC decoders (optional)
Cable Lengths:	6' power cord 15' standard remote control; optional lengths available

FEATURES

Mechanical

- Small size: 9½" high x 20" wide x 28½" long (including lenses)
- Light weight: 75 lbs.
- Easy ceiling mount (full swivel) may be mounted in almost any position
- Rigid mechanical assembly for stability

Controls

Pre-set

- Grey scale level controls — red, green, blue
- Master horizontal/vertical size
- Master horizontal center
- Master vertical linearity
- Sub-contrast
- Sub-brightness
- Sub-color
- Sub-tint

Back panel

- Focus — red, green, blue
- Tube cut-off switches — red, green, blue
- Horizontal/vertical hold
- Horizontal/vertical keystone — red, green, blue
- Horizontal/vertical pincushion
- Horizontal/vertical size — red, blue
- Horizontal/vertical linearity — red, green, blue
- Horizontal/vertical bow — red, green, blue
- Horizontal skew — red, green, blue
- RGB contrast — red, green, blue
- Crosshatch

Remote

- Power on-off switch — LED power/failure indicator
- Standby switch
- Signal source selector switch (RGB, composite video, crosshair)
- Brightness
- Picture control (automatic color tracking)
- Color • Tint • Detail
- Master focus
- Horizontal/vertical centering — red, blue
- Remote control box uses D.C. and low voltages for long-distance cabling compatible with common electric power code requirements
- Standard 115 volt input; 140 volt high line — 90 volt low line

Optical

- Adjustable 4' to 25' wide screen size; uses any screen, flat or curved (not furnished)
- Liquid-coupled lens and liquid-cooled tubes (pat. applied for)
- Easily accessible back panel registration controls
- Parallel lenses for easy screen size change; simple focus (pat. applied for)
- Fully regulated focus, high voltage and registration circuits
- Built-in crosshatch and crosshair generator to facilitate registration

Signals

- Normally driven by remote tuner, tape recorder or other video inputs
- Video processing corrects for video input signals
- Black level adjustable
- Locked positive interlace
- Removable termination for video feed-through
- Sweep reversal plug for rear screen projection
- Integral-comb filter
- I and Q color demodulation
- RGB inputs with separate gain controls, TTL compatible
- Automatic video gain control
- Separate sync or sync on green
- PAL and SECAM options

Power/Safety

- Switch mode power supplies for efficiency, cooler operation and reduced weight
- No high powered 60 cycle transformers, thereby reducing magnetic fields
- 90 volt to 140 volt input
- Full-line isolation; photo-optically coupled high voltage regulator
- Accessible, interchangeable P.C. boards for easy maintenance
- X-ray shielded and sealed; complies with applicable HEW rules
- Arc protected; encapsulated HV leads and connectors
- Overvoltage and overcurrent protection
- Slow high voltage turn on to protect against electrostatic arcing
- Sensitive components diode protected from high voltage static discharges

Accessories

- Ceiling bracket
- Extended remote control cables in 25' increments to 100'

APPLICATIONS

- Teleconferencing
- Education
- Computer Graphics
- Sports
- Entertainment
- Theatres
- News, Information
- Overflow Crowds
- Rentals
- Sales Meetings, Conventions
- Medical Instruction
- Training, Orientation
- Board Room Presentations
- Hospitality, Restaurants
- Advertising Presentations
- Product Introduction
- Close-up Demonstrations

Specifications subject to change without notice. This product covered under U.S. patent #4151554 or other patents applied for.

ELECTRONIC SYSTEMS PRODUCTS, INC.

One Tico Road
Titusville, FL 32780
(305) 269-6680

Telex
ESP TIVL
56-7490

#9 IM 11/81

FIGURE 7.9

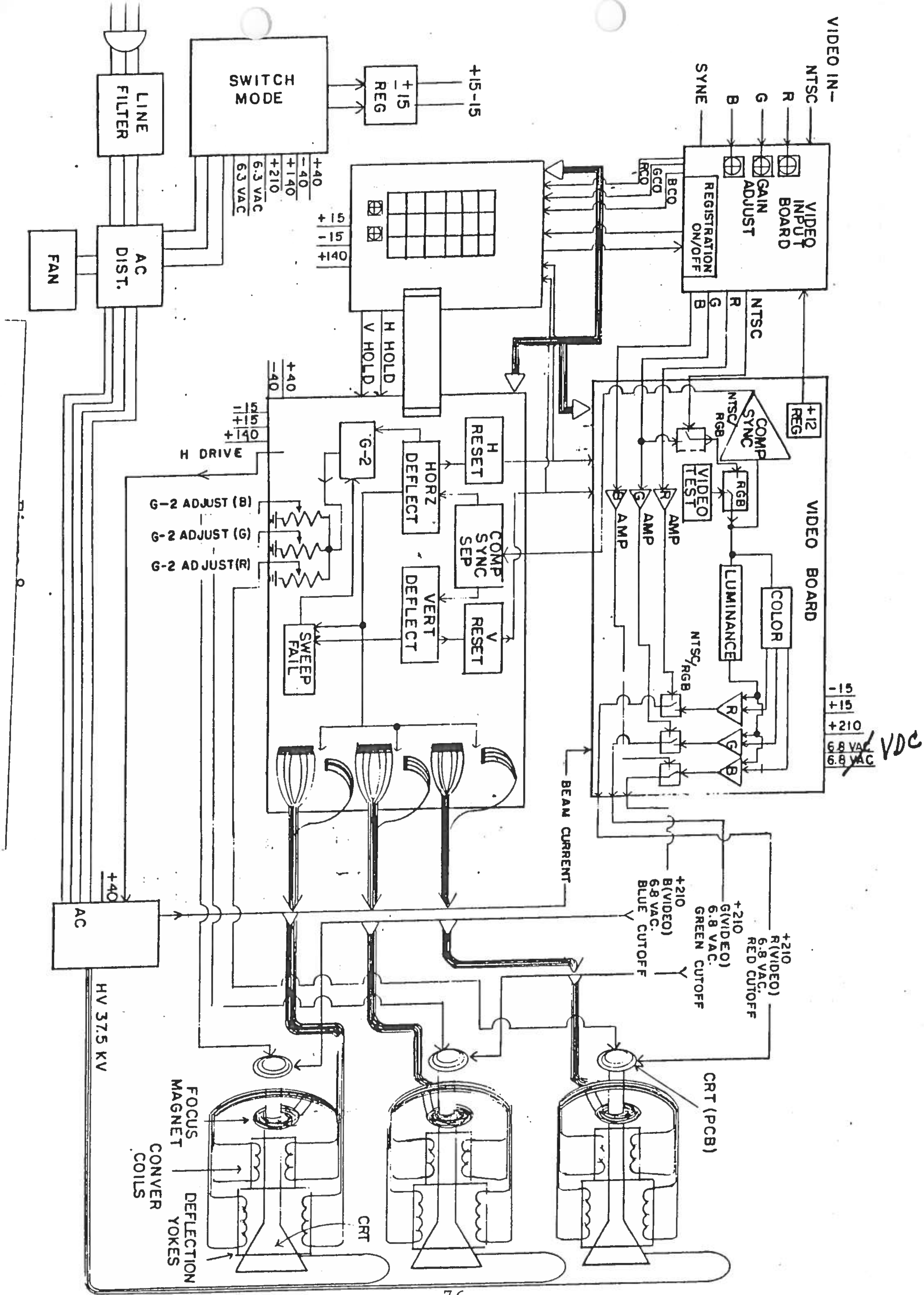

VIDEO IN—
NTSC
R
G
B
SYNE
VIDEO INPUT BOARD
GAIN ADJUST
REGISTRATION ON/OFF
RCO
GCO
BCO
LINE FILTER
SWITCH MODE
+15 -15 REG
+15-15
+40
-40
+140
+210
6.3 VAC
6.3 VAC
FAN
AC DIST.
+15
-15
+140
H HOLD
V HOLD
+40
-40
-15
+15
+140
H DRIVE
G-2
H RESET
HORZ DEFLECT
COMP SYNC SEP
VERT DEFLECT
V RESET
SWEEP FAIL
G-2 ADJUST (B)
G-2 ADJUST (G)
G-2 ADJUST(R)
VIDEO BOARD
+12 REG
COMP SYNC
NTSC
RGB
VIDEO TEST
RGB
AMP
AMP
AMP
LUMINANCE
COLOR
NTSC/RGB
R
G
B
-15
+15
+210
6.8 VAC
6.8 VAC
VDC
BEAM CURRENT
+40
AC
HV 37.5 KV
+210
B(VIDEO)
6.8 VAC.
BLUE CUTOFF
+210
G(VIDEO)
6.8 VAC.
GREEN CUTOFF
+210
R(VIDEO)
6.8 VAC.
RED CUTOFF
CRT (PCB)
FOCUS MAGNET
CONVER COILS
DEFLECTION YOKES
CRT

FIGURE 7.10

drove between the object being looked at and the lighting source. To eliminate this problem it was necessary to mount on the under side of the gantry Sylvania 200 Watt high intensity fluorescent lamps - on each side. In addition, it was necessary to attach two banks of 500 watt quartz halogen General Electric Bulbs on each of the supporting walls. After the installation was made in Florida, it was felt that the presentation needed improvement so it was necessary to add 8 each, 1000 watt quartz Halogen lights on the gantry. With this lighting system, the shadows were eliminated and it was possible to obtain a realistic image from one side of the airfield to another.

7.7 SCREENING

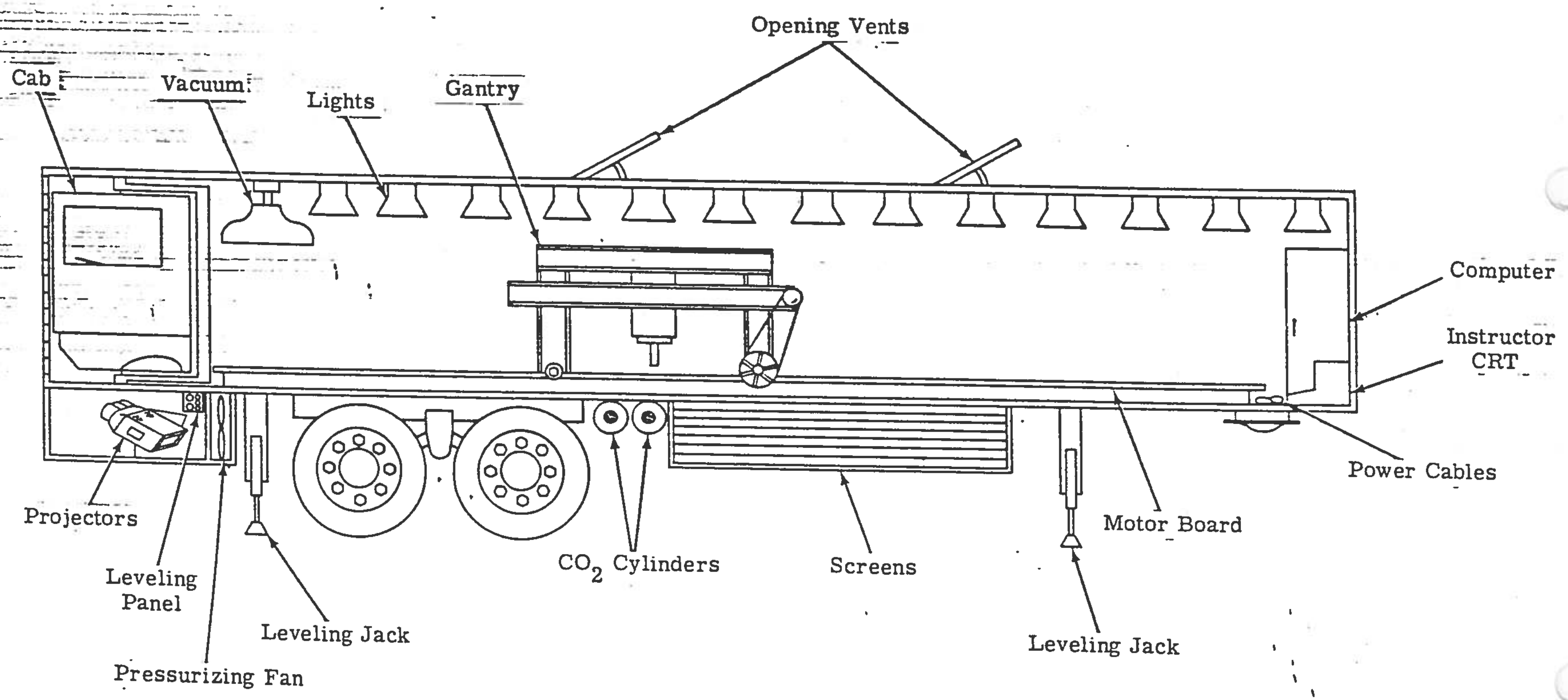
To create the effect of a sky surrounding the air field it was necessary to wrap an off white screen completely around the modelboard. The original screen that we selected and installed was not acceptable to the Air Force because it was not fire resistant. A fire resistant screen was then purchased and installed which was hung on the original frame which extended 4 feet above the modelboard. This screen also served the purpose of reflecting the light on to the modelboard area.

8.Ø TRAILER CONFIGURATION

The possibility of trailerizing the P-4 (Refer Figure 8.1) training system was investigated to facilitate movement from air base to air base. The initial effort showed that it was possible using a standard military type trailer to enclose and transport the complete system. There were a number of trade offs that would have to be made but the trailer was designed to fit into an Air Force cargo plane. There were a number of problems with trailerizing a unit of this type. They are as follows:

8.1 SCREENS:

The screen configuration as presently utilized would not be suitable, as they are too large for transport. It was also determined that instead of having five large screens, there would be approximately 2Ø screens that would be designed to be assembled into the full screen area. These screens would have to be stackable in a storage compartment either inside the trailer or underneath, as shown. This would not be a tremendous undertaking but it would require additional engineering effort and a new mold for the screens.



SIDE VIEW

TRAILER CONFIGURATION

Figure 8.1

8.2 MOTION SYSTEM:

The motion system as presently manufactured would have to be completely redesigned due to the size constraints of the trailer. The trailer itself could be used as a frame for the motion mechanism but there would be a complete redesign effort for the roll, pitch and horizontal motions. In addition the motion algorithm would have to be extensively modified to be compatible with the new motion system.

8.3 GANTRY:

The gantry system would have to be down sized to accommodate the width restrictions of the trailer. In addition, there would be extensive engineering required to strengthen the gantry and build a support system to hold the gantry system during shipment from base to base.

8.4 OPTIC SYSTEM:

The optic system would remain essentially the same except that provisions must be made to quickly remove the critical components such as lense and fiber optic cables for easy and safe storage during transportation.

8.5 MODELBOARD:

The modelboard scale would have to be changed to a smaller scale to have the same type of layout as present with a modelboard that is almost twice the area.

8.6 PROJECTORS/CAMERAS:

Projectors and cameras will be unchanged, however their mountings must be strengthened to withstand the problems of shipping from base to base.

8.7 SMOKE/FIRE SYSTEM:

These systems, again will have to be re-engineered to be able to take the vibrations imposed upon them by shipping.

9.0 DRIVING

9.1 DRIVING ALGORITHM

The first step in developing the driving algorithm was to test an actual vehicle in order to document its turning radius characteristics, as well as the acceleration, and deceleration performance, and the angle of lean in turns. From these tests it was found that the turning radius Ro (feet) in terms of the steering wheel angle (degrees) could be expressed as:

$$Ro = \frac{15252.6}{2\ (O)^{0.769}}$$

The equations of motion were then written. It was seen that in the interests of real time response of the simulator the equations had to be simplified so that solutions could be had in a real time frame. It was decided to ignore the tire slip angles, and in view of the relatively low speeds involved that was a reasonable assumption. The turning circle origin could then be assumed to lie on an imaginary line extending laterally from the center of the rear axle. The motion equations had to be considered about the same point that the drivers eyes were located. This point was located above the front axle. (Refer Figure 9.1 and 9.2)

From the geometric diagram in figure (9.1) the following equations could be deduced.

$$Ro = \frac{15252.6}{2\ (\phi)^{0.767}}$$

$$0 = \tan^{-1} \frac{A}{Ro + B}$$

$$V = \frac{V}{\cos\ \theta_o}$$

Y = obtained from optical encoder on azimuth servo

$$VX = V \cos (Y - 90 - \theta_o)$$

VELOCITY TRANSFORMATION DIAGRAM

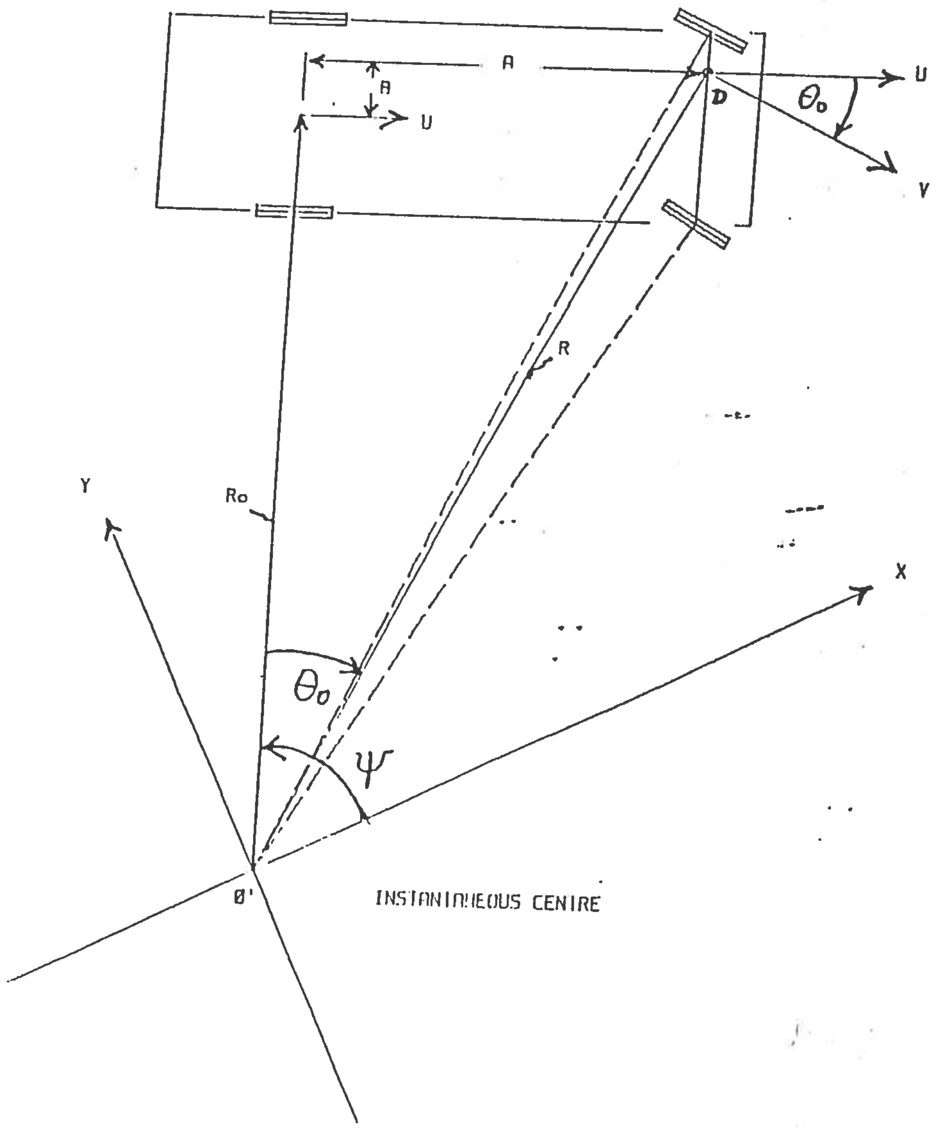


FIGURE 9.1

$$VY = V \sin (Y - 90 - O)$$

$$W = \frac{V}{Ro} \text{ radians/second}$$

In order to simplify control, and in order to ensure that the vehicle did not acquire a sideways motion, it was decided to slave the X and Y velocities to the azimuth angle in the transformation routine. That is vectorial addition of the X and Y velocity components would always result in a vector parallel to V.

The general flow of the driving program is depicted on Figure 9.2.

DRIVING SUBROUTINE SCHEMATIC

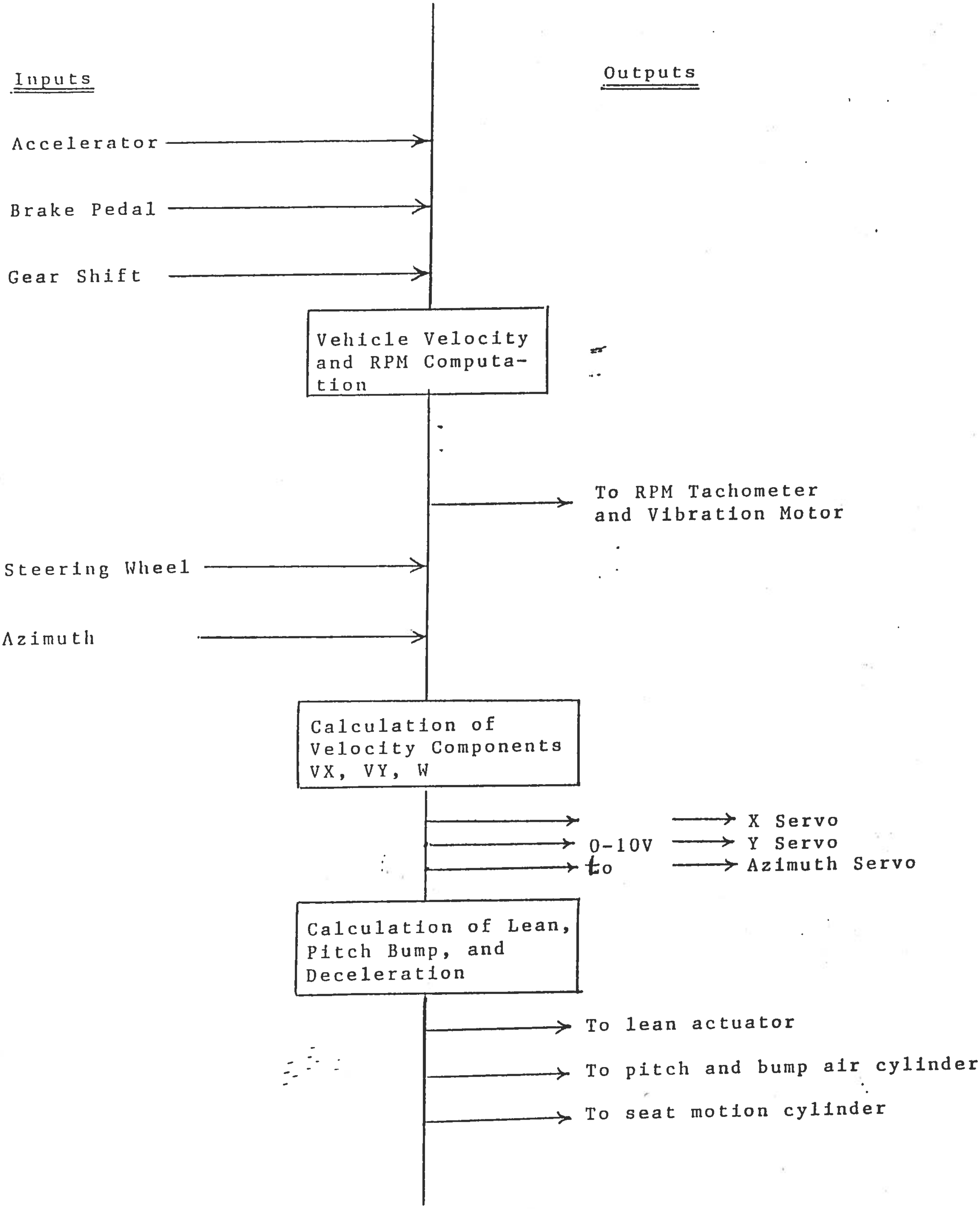


FIGURE 9.2

GLOSSARY OF TERMS:

U : Vehicle velocity vector about the center of the rear axle. Obtained from vehicle parameters and the vehicle velocity subroutine.

Y : Optical Probe-Azimuthal angle measured counterclockwise from the X axis.
Obtained from the optical encoder installed in the azimuth servo.

V : Velocity vector of driver.

O' : Instantaneous center of vehicle turning circle.

Ro : Instantaneous radius of vehicle turning circle.

R : Instantaneous radius of driver turning circle.

D : Location of drivers head

A : Longitutinal displacement of driver from rear axle.

B : Lateral displacement of driver from center line.

O : Angle between Ro and R.

Y : Angle of Ro from X axis.

X : local X axis. Parallel to gantry X axis.

Y : local Y axis. Parallel to gantry Y axis.

VX : X axis component of vehicle velocity.

VY : Y axis component of vehicle velocity.

W : Azimuth angular velocity (radians per second).

O : Steering wheel angle (degrees) obtained from steering potentiometer.

10.0 COMPUTER SYSTEM

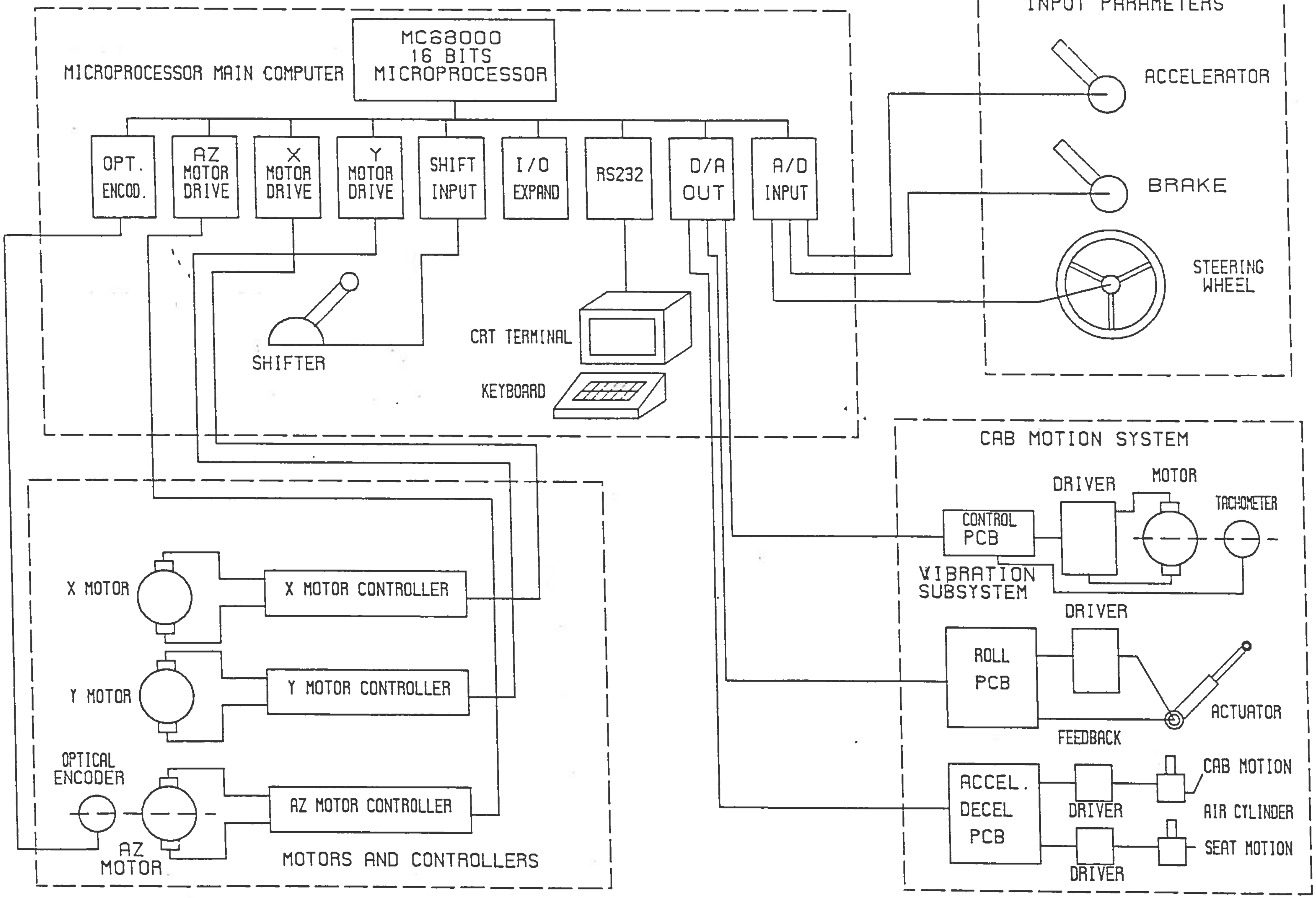
10.1 GENERAL

The computer system has always been based on a Motorola MC68000, 16 bit microprocessor. The original system was designed and build using a wire wrapped board for the main processor. This system was turned on and made functional with the wire wrapped board. As the testing and intergradation of the system continued, the down time caused by the wire wrapped main processor board was unacceptable. Using the same design, a printed circuit board was manufactured and substituted for the wire wrapped board. This microprocessor board worked floorlessly after it was installed.

10.2 COMPUTER SYSTEM

The computer system is based upon a MC68000, 16 bit microprocessor (Refer Figure 10.1) which is operated at a system clock speed of 8 MHz. The operational program is stored on EPROMS resulting in high reliability associated with embeded systems. The microprocessor interfaces to the peripheral via the synchronization methods DTACK and VPA. DTACK is utilized by fast peripherals where as VPA is used by slow peripherals. The computer interfaces to three 16 bit Digital-to-Analog Converters which provide analog control voltages to the motor control system of the gantry. These are the primary outputs of the computer to control all probe motion in the X, Y and Azimuth directions. The computer also interfaces to three analog-to-digital converters which monitor the gass pedal, brake pedal and steering wheel signals. These are inputs along with shifter position, (send through a switch input) that are used to provide input to the simulation equation which calculates the drive motor outputs. The only other input used for calculation of the equation result is the optical encoder input. This input is interfaced to a counter card which determines actual angular position and is accessed via the data position of the support beam (actually a

ELECTRICAL SYSTEM BLOCK DIAGRAM



tube) is accomplished with a linear actuator which causes the cab to tilt side to side. The time of the pulses to the air cylinders is under control of an 8 bit 1 MHz microprocessor which interfaces to the main computer via the analog outputs of MPH and deceleration. The calculations of pulse width come directly from an adjustable constant which scales the deceleration input. When deceleration is maximum the cylinders fully engaged with the vent closed. When deceleration is zero the cylinder is disengaged and the vent is opened. The MPH input is used to simulate bumps on and off the road. It produces sharp impulses to the cylinder in a random manner thus simulating the randomness of normal on and off road conditions. The off road impulses are more severe and occur at a greater frequency than the roadway impulses. The other motion platform degree of freedom is also under the control of an 8 bit microprocessor which interfaces to the main computer via the W2 R lateral acceleration output. This feedback control loop is closed by a position potentiometer within the linear actuator. The microporcessor moves the motor to minimize the difference between the voltage from the main computer and the voltage from the feedback potentiometer. The system is dynamically adjusted to eliminate overshoot and produce a pulse width modulated signal to the actuator motor. Both of these processors operate independently off the main computer and are, therefore, able to run at full speed without slowing the main loop at all.

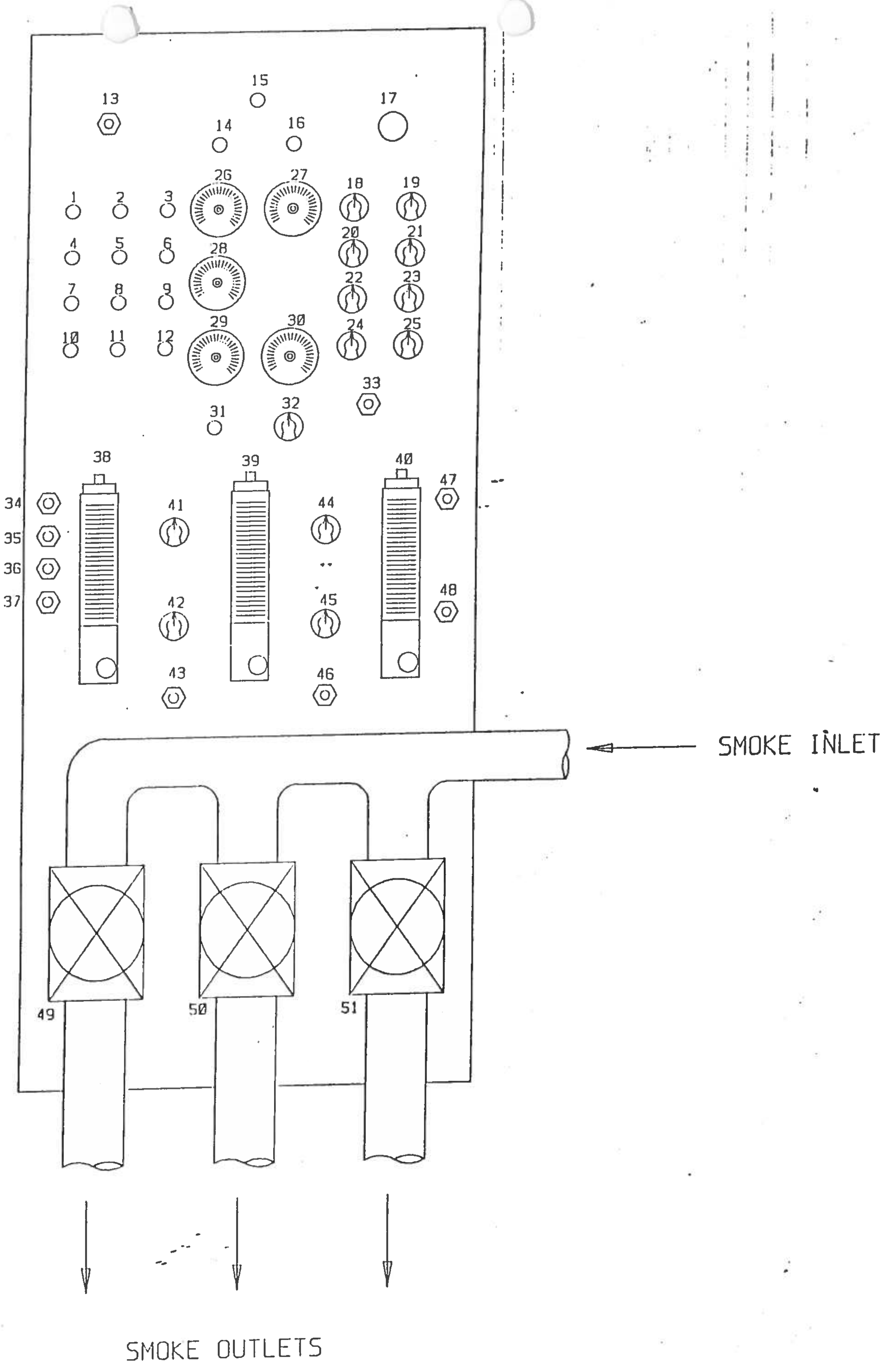
11.Ø INSTRUCTOR'S CONTROL PANEL

11.1 GENERAL

The instructor's control panel is a single sheet of finished aluminum that allows the instructor to monitor and control the various functions of the fire, smoke, etc. Because of its location right behind the driver, the instructor has the ability to monitor the operator's driving skills and fire fighting techniques. The instructor has the ability to freeze the driving situation at any time but he does not have control of direction, velocity and braking of the vehicle. The Simulator is under the control of the driver/operator with the instructor setting up problems in the various scenarios and observing the driver/operator's reactions to these problems. The main function of the instructor is to observe both the driver's operations and the operation of the probe on the modelboard. This is accomplished by the using of a one way mirror mounted next to the console that allows the oporator to observe the probe at all times to insure the driver is not going to damage the system.

11.2 SMOKE AND FIRE CONTROLS

The smoke and fire controls are the major input for the instructor. The smoke system, described in Section 5, eject a mist of smoke through a PVC pipe that manifolds it to three separate valves. (Refer Figure 11.1 and 11.2, items 49, 5Ø, 51) These are quarter turn ball valves that allow modulation of the smoke from full off to full on or at any variable position between. The pressurized smoke is then brought to each of the three fire pits as adjusted. The instructor then will control the rate of rise of the smoke by adjusting the helium flow on flowmeters 38, 39 and 4Ø. The instructor gets visual feedback by observing the smoke through the one-way mirror. The fire intensity is controlled by control knob 44, which controls the voltage to the quartz Halogen fire lights. The various gages on the top of the panel are Ø - 1 milliamp DC gages that act as a slave to the operator's gages in the cab. This allows the instructor to closely monitor the driver's performance.



INSTRUCTORS CONSOLE

FIGURE 11.1

CONSOLE GUIDE

1. Beacon Indicator Light
2. Flood Indicator Light
3. Spot Light Indicator Light
4. Headlight Indicator Light
5. Dome Indicator Light
6. Flashing Valve Indicator Light
7. Booster Heat Indicator Light
8. Power Divide Indicator Light
9. Short Light Indicator Light
10. Differential Lock/Unlock Indicator Light
11. Run Indicator Light
12. Cycling Indicator Light
13. Off Road Switch (Push Button)
14. Engine Start Switch
15. Master Switch
16. Engine Off Switch
17. Console Light
18. Engine Oil Control Knob
19. Engine Pressure Control Knob
20. Water Temperature Control Knob
21. Trans Temperature Control Knob
22. Voltage Control Knob
23. Fuel Control Knob
24. Pressure Control Knob
25. Water Tank Temperature Control Knob
26. MPH Gage
27. Coolent Pump Pressure Knob
28. RPM Knob
29. Foam Flow Gage
30. Water Pump Pressure Gage
31. Foam On Switch
32. Water Pump Pressure Control Knob
33. Glare Simulation Knob
34. Spare Switch
35. Spare Switch
36. Wind Switch
37. Fire Pit #3 Rotating Lights
38. Fire Pit I Heilum Gas Flow Gage
39. Fire Pit 2 Helium Gas Flow Gage
40. Fire Pit 3 Helium Gas Flow Gage
41. Fire Pits Select Switch
42. Foam Level Knob
43. Solenoid Switch (Smoke Generator)
44. Fire Intensity (Variac) Knob
45. Water Level Knob
46. Vent Switch
47. Battery On Switch
48. Runway Lights Switch
49. Smoke Valve #1
50. Smoke Valve #2
51. Smoke Valve #3

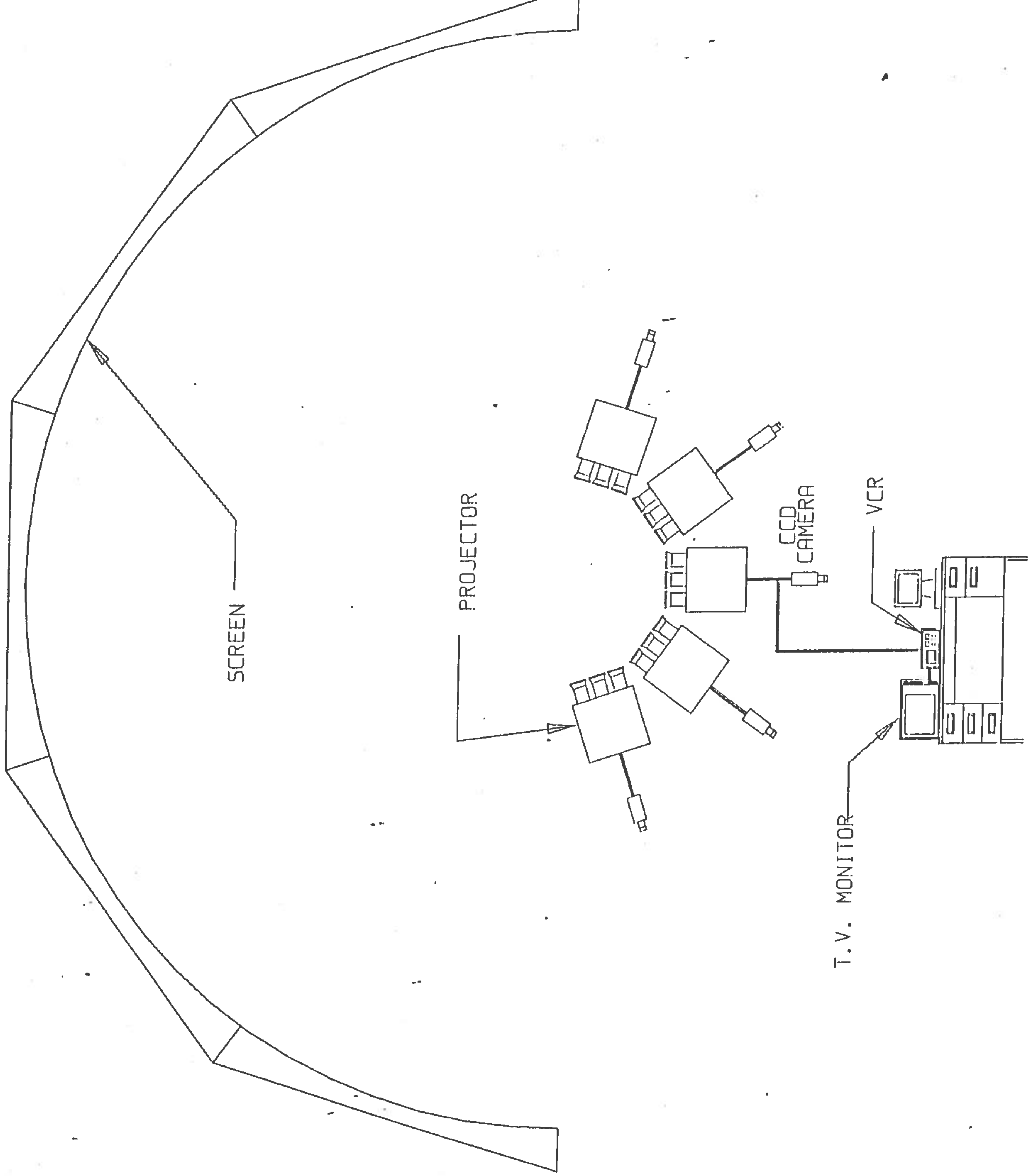
FIGURE 11.2

12.Ø VIBRATION

The P-4 vehicle required the simulation of normal vehicle vibration as a function of engine speed. The original design used a 1/8 horsepower motor driven at variable speed with an eccentric weight mounted on the shaft. This system did not give the realistic vibration needed as the vibration was too light. A new, much heavier motor was installed and this motor is a 3/4 horsepower, 12 volt DC pulse width modulated with tachometer feedback. The pulse width modulation is controlled directly from the D to A output of the main microprocessor. The motor is manufactured by Honeywell with the eccentric 1/2 pound disk mounted off center.

13.Ø MAIN SCREENS

The main screens were manufactured on a mold. The manufacturing process consists of laying up figerglass on a mold similar to boat hull construction. The screens are concave and have a 5 inch flange extending from both the top and bottom and the sides, away from the viewing area. The screens are ap


SCREEN
PROJECTOR
CCD CAMERA
VCR
T.V. MONITOR

proximately 3/4 inch thick, as are the flanges. The flanges allow the screens to be bolted together to make a rigid semicircle that is 11 feet high and 28 feet in diameter. The screens are finished with a flat white paint. (Refer Figure 13.1)

The intersect point between the projectors on the viewing side of the screen was covered with a flat black strip three inches across, and 11 feet high. The purpose of this strip was to eliminate any possible mismatches between adjacent projectors.

One of the initial problems with the Simulator was low light levels being projected on the main screen. To improve the video gain, a special screen was manufactured that was grooved to reflect all the projected light directly back into the center of the cab. This screen was covered with a highly reflective paint. This change increased the video gain by a factor of 5Ø. This change was rejected because it would have been very expensive to remanufacture the screens to this new design.

14.Ø PRELIMINARY CRASH RESCUE SIMULATOR--PRODUCTION COST ESTIMATE AND TRADE OFF

14.1 COST ESTIMATE

The estimate for production of 14 Crash Rescue Simulators was derived from the prototype. This information identified all major items to be priced. Additional discussions were held with design and manufacturing engineers to assist in obtaining comparison for similar types of simulators which have been quoted or purchased. The hourly rates were estimated on the basis of production at a typical electronics manufacturing facility. All the necessary production hours of material to fabricate and assemble the simulator have been included. Support labor such as quality engineering, liason, manufacturing support, and program management has been estimated. The basic fabrication estimated was made using dollars and hours per component of the simulator based on the past experience of the prototype device. The balance of the estimate was based on quotes obtained and from judgemental estimates. The estimate was made for 14 units in various lot sizes.

Lot	Lot Size	Unit Cost
1	1	925,000
2	2	832,500
3	3	749,250
4	3	674,325
5	3	645,250
6	2	625,741

14.2 TRADE OFFS TO REDUCE COST

As previously discussed, there has been a trade off study performed to determine the feasibility of installing a simulator in a trailer. Among the trade off possibility that would reduce the cost and increase the versatility of the simulator would be to replace the present projectors with higher quality projectors that are available in the market place at lower cost. These projectors can double the intensity of the screen presentation. Another change that would be desirable to use a newer design CCD Camera that is more sensitive to low light levels. Again, because of the recent advancements in the video fields these items are becoming less costly. Since the molds are already manufactured, a great part of the initial cost of additional units will be lowered. The optical probe system should be redesigned with slip rings to eliminate the problem of limited rotations of the system. The fiber optic cable will have to be manufactured and handled with greater care, to eliminate the broken fiber problems that we have experienced on the prototype. These changes can all be incorporated in the first production unit and proven out.